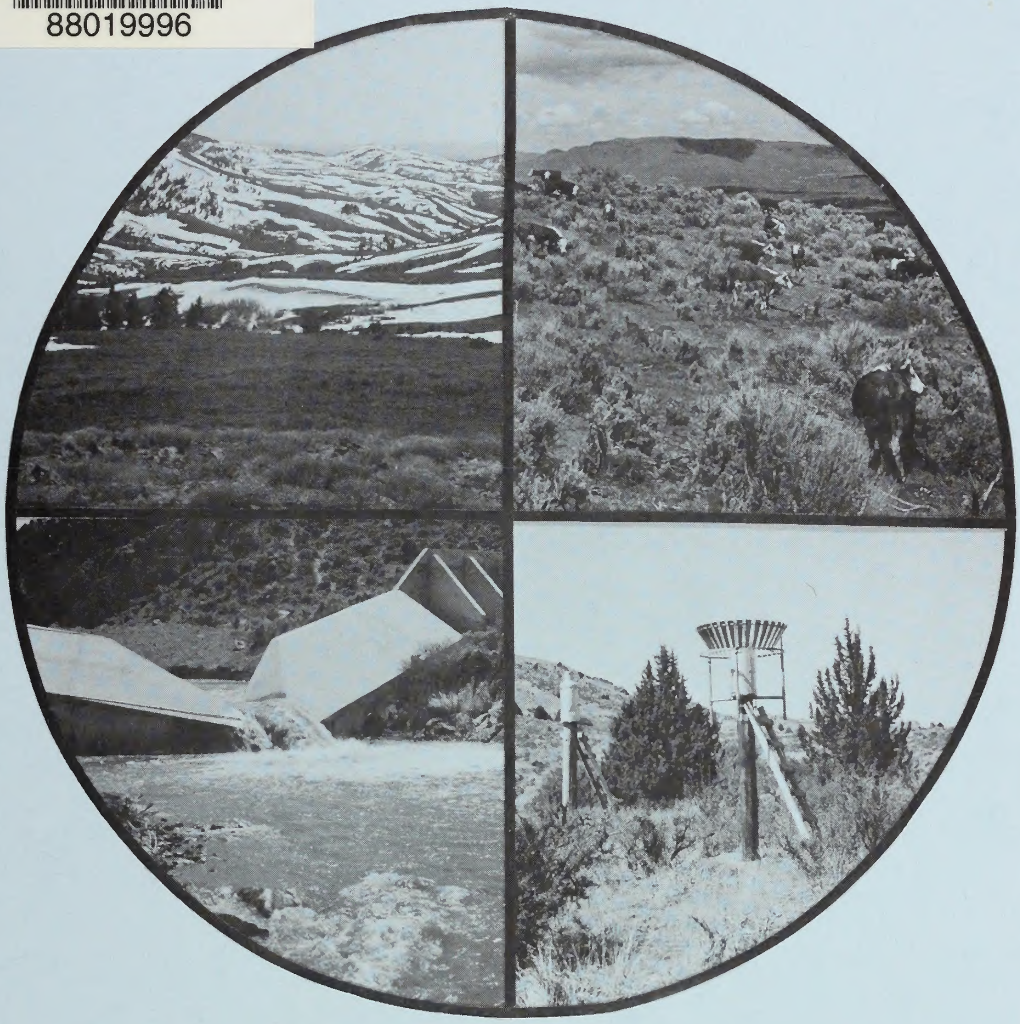
VOLUME II--COMPREHENSIVE REPORT

ARS/BLM COOPERATIVE STUDIES

REYNOLDS CREEK WATERSHED



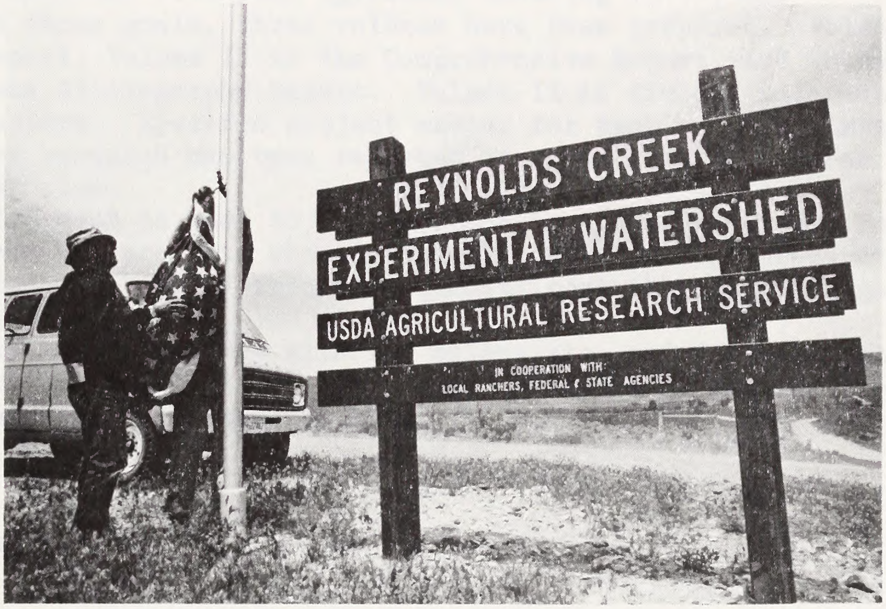
U.S. Department of Agriculture

Agricultural Research Service

Northwest Watershed Research Center

Boise, Idaho

VOLUME II--COMPREHENSIVE REPORT



ARS/BLM COOPERATIVE STUDIES

PREFACE

The final year's effort of the current BLM-ARS cooperative agreement was to prepare a project completion report of BLM-ARS research results for the period 1968-1982. The report was to highlight results from the recently completed five-year agreement covering 1977-1982.

To meet these goals, three volumes have been prepared. Volume I is the Summary Report, Volume II is the Comprehensive Report, and Volume III is the Data and Bibliography Report. Volume II is divided into subject matter chapters. Specific subject matter for each year of BLM-ARS cooperative research has been reported in an Interim Report for that year's work plan.

Acknowledgment is made to staff of the Northwest Watershed Research Center, past and present, whose dedication has made the preparation of this report possible and insured a quality contribution to rangeland hydrology.

Cooperative interchange with BLM scientists, and district, state, and national representatives has greatly influenced and improved research emphasis and resulting publications.

October 1983

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Chapter 1

PRECIPITATION

CLAYTON L. HANSON, Agricultural Engineer

Chapter 1

PRECIPITATION

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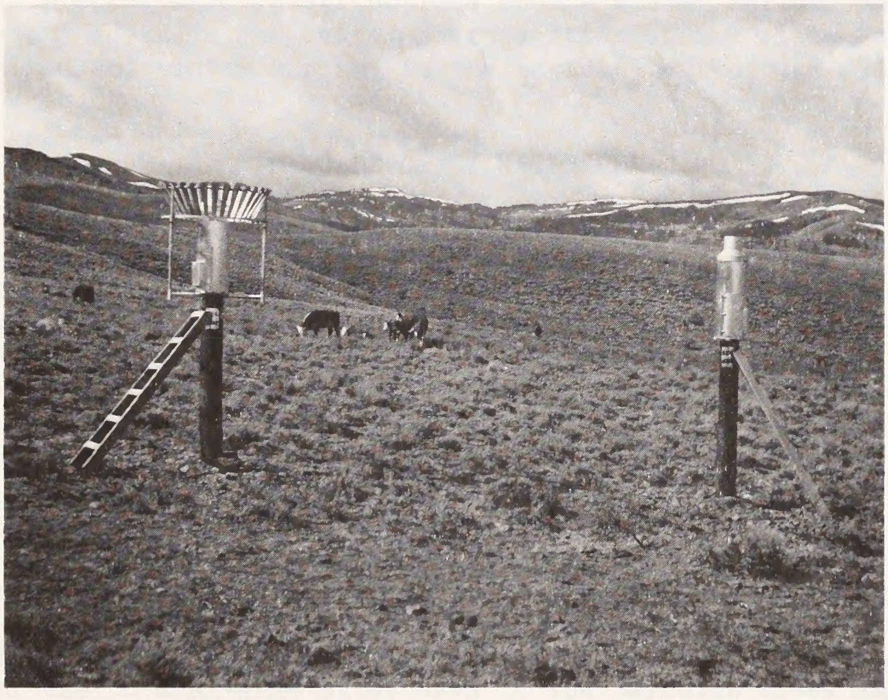
Routine Precipitation Gage Service



Shielded and Unshielded Precipitation Gages

INTRODUCTION

Spatial and seasonal precipitation distributions were not part of the ARS-BLM cooperative studies until FY 78. However, this section will include both data summaries and analyses for the complete 21-year (1962-1982) record, since this information supports other sections of the summary report. The following topics will be discussed in this report: 1) regional climatology; 2) annual and monthly precipitation distribution on Reynolds Creek; and 3) regional annual and monthly precipitation generation.

Idaho Precipitation

Located some 300 miles from the Pacific Ocean, Idaho's major moisture source is maritime air from prevailing westerly winds. The westerly winds are able to carry more moisture into northern Idaho through the Columbia River Gorge than to southern Idaho, because of the mountain ranges to the west. During the summer, some moisture is brought in from the Gulf of Mexico at high levels, which produces thunderstorms, particularly in the eastern part of the state.

Precipitation ranges widely in Idaho, with large areas of the northeastern valleys, Snake River Plains, and southwestern valleys, such as Lower Reynolds Creek, receiving less that 10 inches annually and some mountainous areas receiving over 60 inches annually (Hanson et al. 1980, Rice 1971).

Seasonal precipitation distributions show a winter maximum and summer minimum in the northern and southwestern portion of the state, and a summer maximum and winter minimum in the eastern part of the state.

REYNOLDS CREEK WATERSHED

Precipitation Gage Network

The original gage network, established in 1960-61, consisted of 83 unshielded recording gages. During the winter, most of the precipitation that falls on the watershed is snow, and the network of single, unshielded gages was not measuring snow precipitation adequately. Therefore, during 1967-68, the network was converted to 46 dual-gage installations (Figure 1.1). (See Chapter 6, Resource Monitoring, for further details on the dual-gage system.) After a thorough analysis of records to determine which gage sites best represented different areas of the watershed, the dual-gage network was further reduced, during 1976-77, to 19 sites which were in use at the end of 1982. Table 1.1 lists the 19 dual-gage sites, their elevation, and dates of operation so precipitation data can be associated with other sections of this report. Figure 1.1 shows the location of the 38 dual-gage sites used in the Reynolds Creek analyses, which follows in this report. Monthly and annual data for the 19 numbered sites in Figure 1.1 are listed in Volume III, Section A of this report.

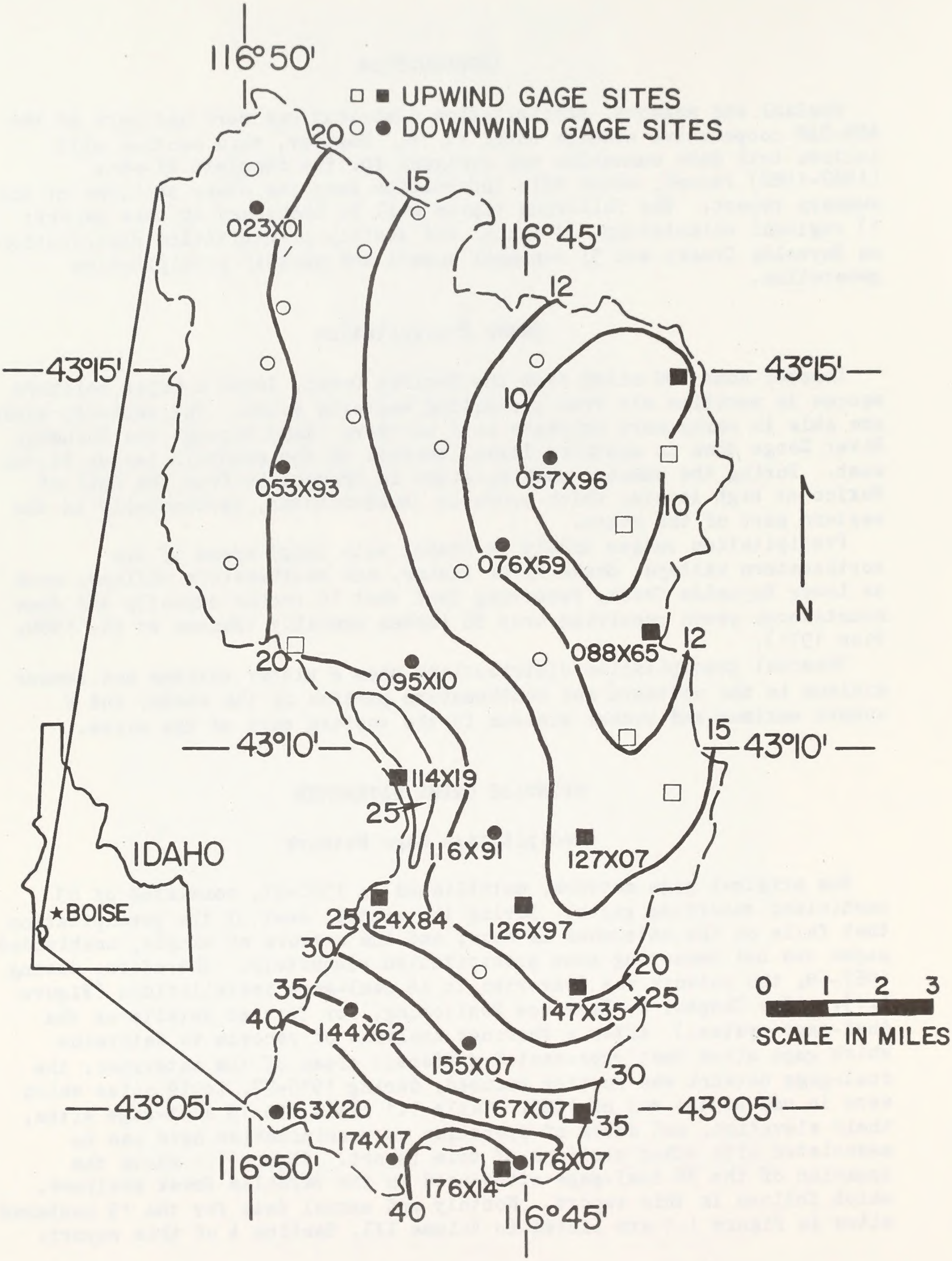


Figure 1.1.--Reynolds Creek Experimental Watershed precipitation network; isohyets in inches.

Table 1.1.--The 19 dual-gage precipitation sites on Reynolds Creek Experimental Watershed in operation at the end of 1982[1/].

Site No.	Elevation (ft)	Record Length (yrs)	Site No.	Elevation (ft)	Record Length (yrs)
023X01	4880	1962-82	127X07	5410	1962-82
053X93	4950	1968-82	144X62	5930	1962-82
057X96	3885	1962-82	147X35	6140	1962-82
076X59	3915	1962-82	155X07	5410	1962-82
088X65	4410	1962-82	163X20	7100	1962-82
095X10	4880	1962-82	167X07	6600	1962-82
114X19	5885	1962-82	174X17	6760	1962-82
116X91	4770	1962-82	176X07	6800	1962-82
124X84	5920	1962-82	176X14	6880	1968-82
126X97	5460	1962-82			

[1/] See Volume III, Section A for monthly summaries. Daily records are available on magnetic tape.

Annual and Monthly Precipitation

The average annual precipitation on the Reynolds Creek Experimental Watershed ranged from about 10 inches on the low elevation (3,800 feet), on northeastern areas to about 43 inches at the high elevation (7,100 feet), southwestern areas of the watershed (Figure 1.1). These precipitation differences were associated with elevation and storm patterns, which move onto the watershed from the west and southwest. This storm pattern caused high precipitation on the south and west section of the watershed and precipitation shadows on the north and northeast sections.

Precipitation on the watershed increased with elevation and showed a seasonal pattern, with the lowest amounts in July and greatest amounts in December and January (Table 1.2). The location of the four sites listed in Table 1.2 are shown in Figure 1.1. The data in Table 1.2 show that 41 percent of the average annual precipitation fell from May through October at the low elevation, 3,915 feet, station 076X59; whereas, only 24 percent fell during the same period at the high elevation, 7,100 feet, station 163X20. These percentage differences show that a greater proportion of the annual precipitation fell during the winter at high elevations than at the lower elevations.

Monthly and annual precipitation at the four sites (Table 1.2) illustrates how precipitation varied by month with elevation. July had the least average precipitation at the four sites, and ranged from .28 inches at 076X59 to .66 inches at 163X20. The greatest average monthly precipitation was during January, and varied from 1.44 inches at 076X59 to 7.80 inches at 163X20. In general, July, August, and September were the driest months and November, December, and January were the wettest. June precipitation was greater than May or July precipitation at the two low elevation sites. This June maximum at the two Reynolds Creek Stations (076X59 and 116X91) did not show up in the 42-year (1940-81) record at the Boise Airport, where the average monthly precipitation for each month, February through June, ranged from .98 inches to 1.21 inches and then decreased to .21 inches in July (Figure 1.2). The 20-year (1962-81) record at Boise also indicates that, during the period, May precipitation was below average and June precipitation was about average. The low monthly precipitation (Table 1.2) varied from none at least one year during July, August, and September at all sites, to more than five times the monthly mean during August at site 076X59. The yearly maximum precipitation varied from 1.31 times the average at 076X59 to 1.46 times the average at 155X07. The year with the least precipitation ranged from 0.61 times the average at 076X59 to 0.75 times the average at 163X20, which shows that there was less yearly variation at the high elevation during this period.

Annual Precipitation

Distribution on the Watershed

Hanson et al. (1980) reported a linear relationship between annual (calendar year) precipitation and elevation. They also found two precipitation-elevation relationships, one for the east side and one for the west side of the watershed, were more representative of conditions on the watershed than a single equation. Further analysis showed that the gage sites located along the southern and western borders of the watershed

Table 1.2.--Monthly and annual precipitation at four sites on the Reynolds Creek Experimental Watershed, 1962-1981.

	076X59 (3915 ft)			116X91 (4770 ft)			155X07 (5410 ft)			163X20 (7100 ft)		
Month	Average	High[1/]	Low[2/]	Average	High	Low	Average	High	Low	Average	High	Low
January	1.44	4.16	.28	2.62	6.29	.64	4.42	10.54	1.06	7.80	16.41	2.73
February	.79	1.71	.23	1.57	3.08	.40	2.74	4.94	.68	4.65	10.01	1.17
March	.90	2.56	.09	1.66	4.13	.12	2.79	6.19	.68	4.65	10.74	.91
April	1.01	3.15	.12	1.80	3.88	.40	2.37	4.87	.32	3.88	8.87	.74
May	.88	3.67	.10	1.29	3.16	.24	1.81	3.52	.38	2.69	7.46	.78
June	1.30	3.05	.29	1.55	4.17	.49	1.77	4.34	.45	2.28	4.62	.33
July	.28	1.04	.00	.38	1.13	.00	.59	1.84	.00	.66	2.06	.00
August	.71	3.96	.00	.67	3.01	.00	.99	4.17	.00	1.11	5.60	.00
September	.55	2.55	.00	.78	2.85	.00	1.02	3.27	.00	1.28	3.60	.00
October	.85	2.86	.01	1.46	5.14	.06	2.03	7.14	.07	2.57	7.17	.06
November	1.21	2.36	.15	2.13	3.98	.09	3.53	7.05	.22	5.60	11.90	.80
December	1.28	5.21	.07	2.49	8.62	.18	4.02	12.25	.23	6.44	14.87	.67
Total	11.20	14.63[3/]	6.88[4/]	18.40	24.58	12.59	28.08	41.09	19.40	43.61	57.95	32.61
Summer Total[5/]	4.57			6.13			8.21			10.59		
Winter Total[6/]	6.63			12.27			19.87			33.02		

1/ Wettest month of record.

2/ Driest month of record.

3/ Wettest calendar year of record.

4/ Driest calendar year of record.

5/ Total precipitation, May - October.

6/ Total precipitation, November - April.

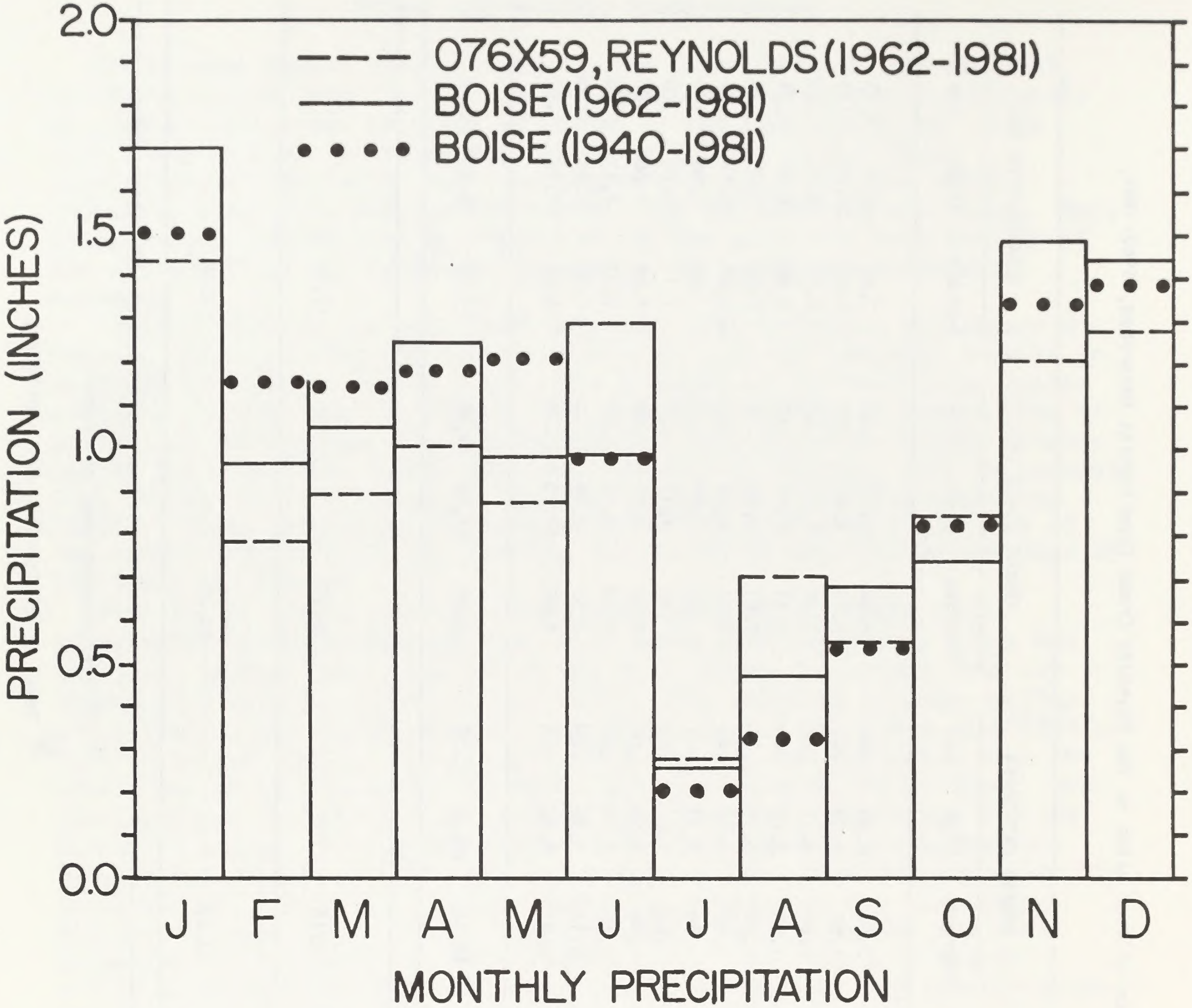


Figure 1.2.--Monthly precipitation at Reynolds Creek Experimental Watershed, site 076X59 and Boise Weather Service office, Airport Station, Idaho.

were measuring precipitation coming upslope onto the watershed from the south and west, and thus, were in the same precipitation group as the sites on the east side of the watershed. This gage site stratification, as shown in Figure 1.1, indicates that precipitation amounts increase very rapidly just leeward from the watershed boundary, and then decrease as the elevation decreases to the center of the watershed.

Precipitation then increases on the upwind (east) side of the watershed, but at a slower rate. Gage sites shown as downwind sites in Figure 1.1 are located leeward of the watershed boundary and west of Reynolds Creek. Gage sites shown as upwind sites are located east of Reynolds Creek and along the southern and western boundary of the watershed. These elevation relationships are illustrated in Figures 1.3 and 1.4, and in Hanson (1982).

The following equations describe the precipitation-elevation relationships for the downwind and upwind gage sites:

$$\text{Downwind} \quad Y = -29.02 + 0.0102X \quad (R^2 = 0.920) \quad n = 24 \qquad [1.1]$$

$$\text{Upwind} \quad Y = -24.88 + 0.0078X \quad (R^2 = 0.855) \quad n = 14 \qquad [1.2]$$

where Y is the average annual precipitation (inches) and X is elevation (feet). The coefficients of determination (R^2) represented in Figure 1.4 show that there is a good annual precipitation-elevation relationship for both groups of gage sites. Annual precipitation increases at a rate of 10.20 in per 1000 ft on the west side (downwind) of the watershed and at a rate of 7.80 in per 1000 ft on the east side (upwind).

The precipitation distribution illustrated in Figure 1.3 shows a small watershed within a mountain range in southwest Idaho, and, thus, represents a different size scale from most papers written on annual precipitation distribution in mountainous areas. Papers by Dyunin (1974), Dyunin and Matvienko (1974), and Dyunin and Kotlyakov (1980) state that this precipitation distribution was caused by the "deformation effect of mountain relief upon the wind flow," which causes the snow accumulation zone just leeward of the watershed boundary.

The magnitude of the difference in annual precipitation between gage sites on the watershed boundary and 1,600 feet leeward can be seen from the 1968-1981 record from gage sites 176X07 and 176X14 (Figure 1.1). Average annual precipitation at site 176X14 was 30.65 inches for the 14-year period, while at site 176X07, it was 40.69 inches, a 33 percent increase. Site 176X07 is 80 feet lower than site 176X14. As would be expected, this difference in annual catch was due primarily to winter precipitation. Average August precipitation at the two sites was the same, whereas the average January precipitation was 1.5 times greater at site 176X07 than site 176X14. Some of this difference may be attributed to measuring errors, but ongoing studies indicate that most of the difference is due to the location of gage sites.

The precipitation-elevation relationships shown in Figure 1.5 compare the Reynolds Creek Watershed area with others in the intermountain region. The relationship by Riggs and Moore (1965) for northern Nevada, by Peck and Brown (1962) for the eastern slopes of the Wasatch range, and for the Boise Front have a lesser slope than found for the Reynolds Creek Watershed. The relationship obtained for Saval Ranch, Nevada is about the

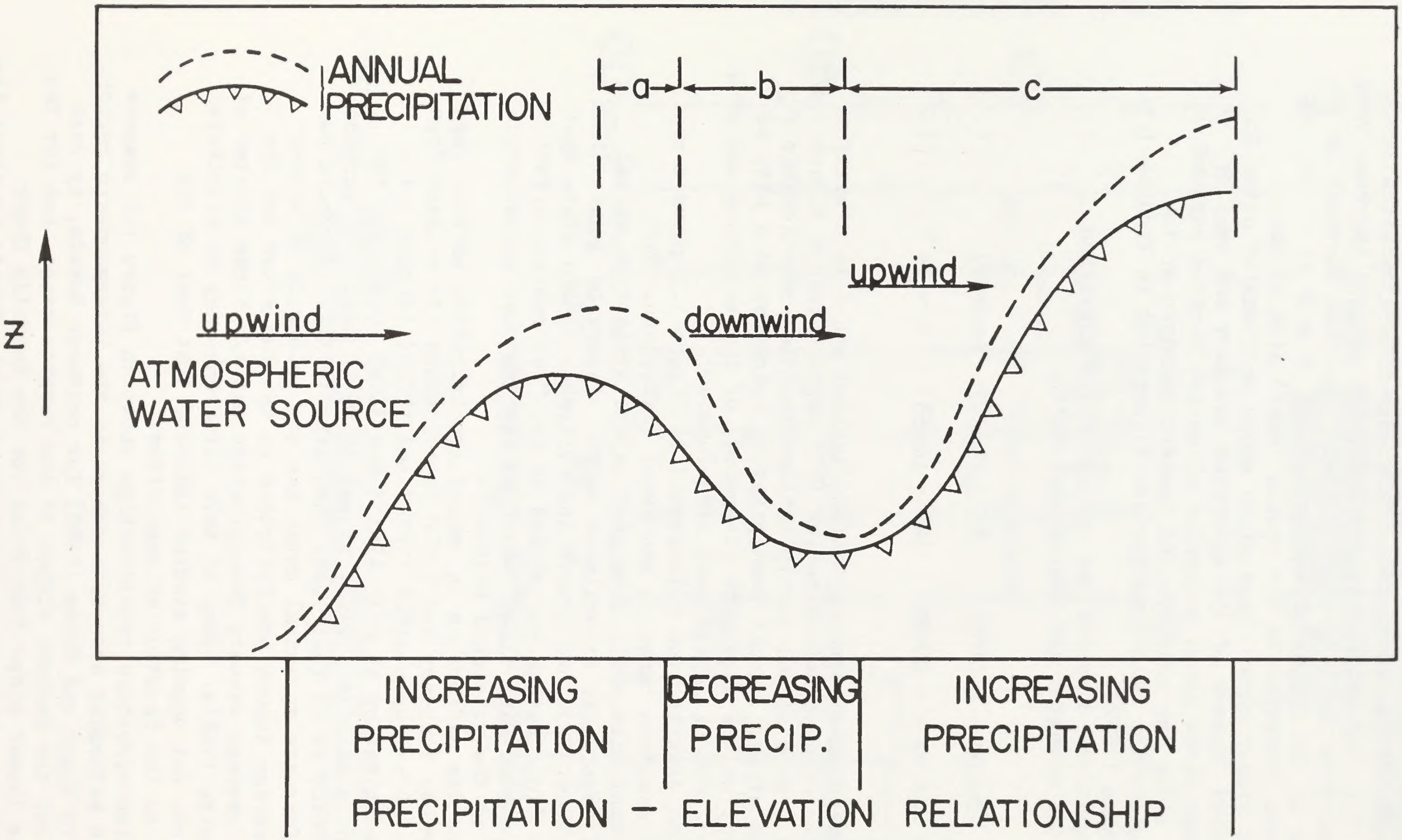


Figure 1.3.--Schematic diagram of the annual precipitation distribution on a small watershed within a mountain range: a. location of the greatest precipitation; b. zone where precipitation decreases as elevation decreases, but the annual total is greater than at the same elevation on the upwind side of the valley; c. zone where precipitation increases with increasing elevation, but the annual total is less than at the same elevation on the downwind side of the valley.

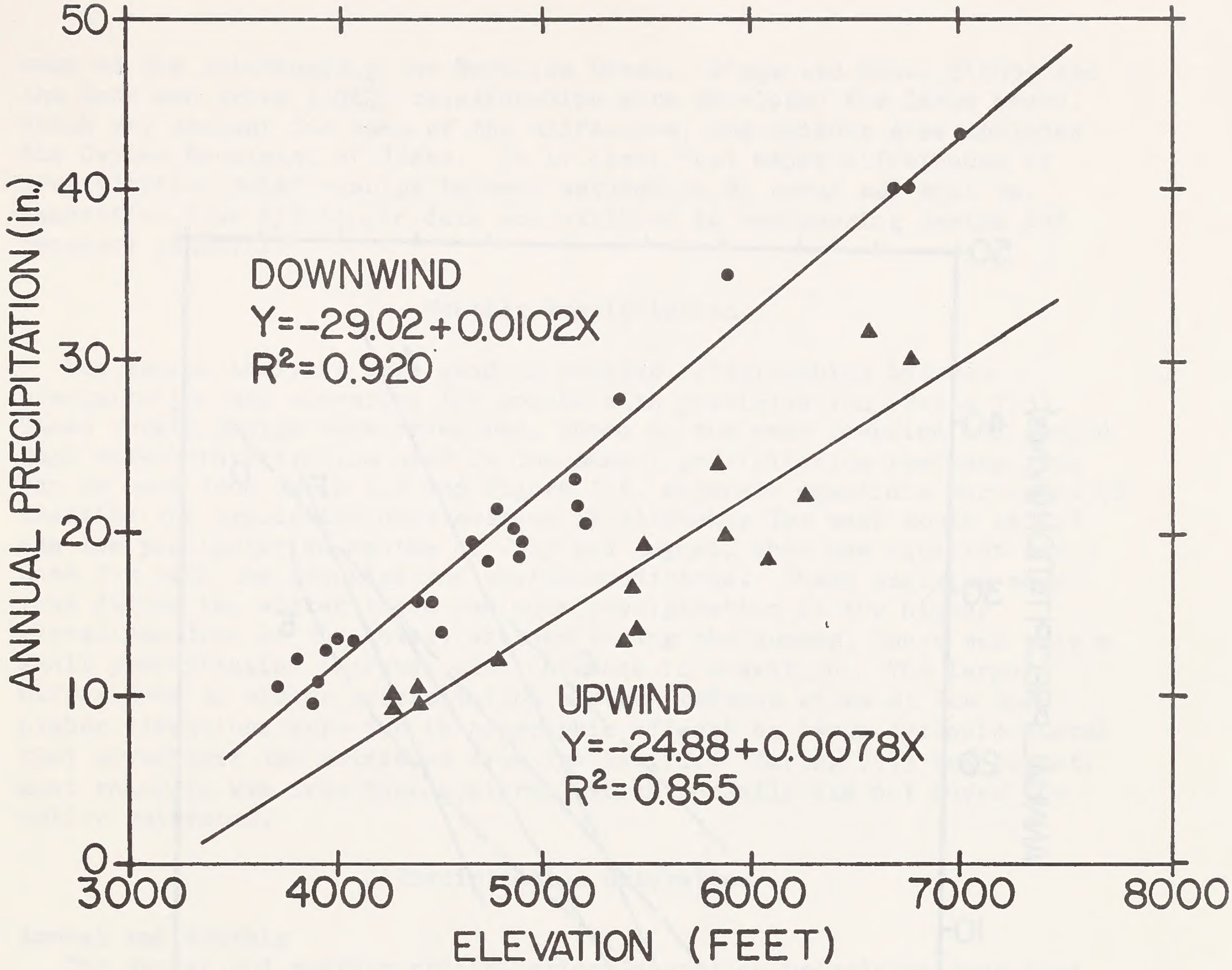


Figure 1.4.--Relationship between elevation and mean annual precipitation.

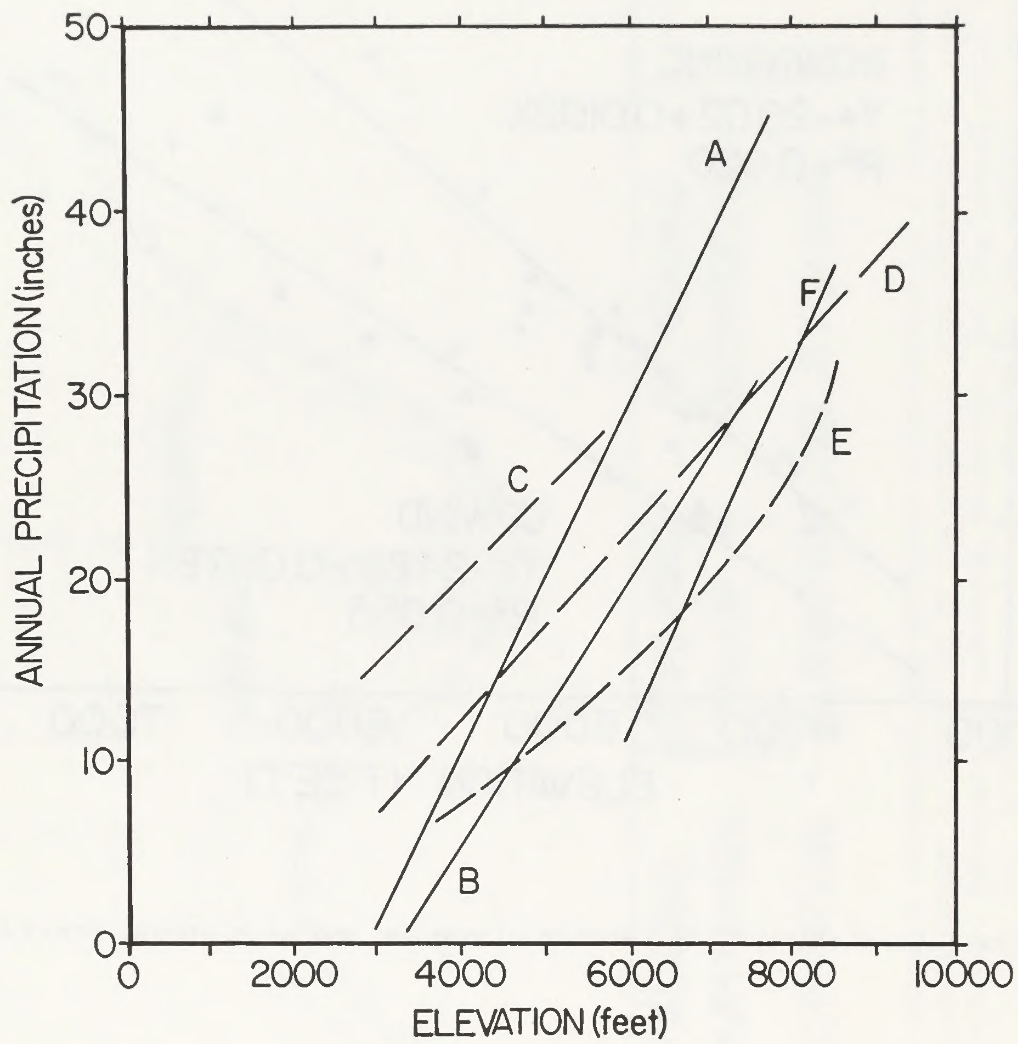


Figure 1.5.--Relationship between elevation and annual precipitation: A. downwind side of Reynolds Creek Watershed; B. upwind side of Reynolds Creek Watershed; C. line based on a 4-year record from the upwind side of the Boise Front, near Boise, Idaho; D. eastern (downwind) slopes of the Wasatch Front, Utah; E. Nevada-Region; and F. line based on a 2-year record from the Saval Ranch, near Elko, Nevada.

same as the relationship for Reynolds Creek. Riggs and Moore (1965) and the Peck and Brown (1962) relationships were developed for large areas, which may account for some of the difference, and neither area includes the Owyhee Mountains of Idaho. It is clear that major differences in precipitation relationships between watersheds do occur and must be quantified when hydrologic data are utilized in engineering design and resource planning.

Monthly Precipitation

Regression analyses were used to develop relationships between precipitation and elevation for months with precipitation (Table 1.3). These relationships were developed, based on the same downwind and upwind gage site stratification used in the annual precipitation analyses. As can be seen from Table 1.3 and Figure 1.6, separate equations were used to describe the precipitation-elevation relationship for each month except the low precipitation months of July and August, when one equation was used for both the downwind and upwind conditions. These analyses show that during the winter there was more precipitation at the higher elevations than at the lower, whereas during the summer, there was only a small precipitation increase with increase in elevation. The large differences in winter precipitation amounts between sites at low and higher elevations were due to orographic effects on large cyclonic storms that moved over the watershed from the Pacific. During July and August, most rainfall was from thunderstorms, which normally did not cover the entire watershed.

Precipitation Generation

Annual and Monthly

The annual and monthly precipitation generation procedures developed from Reynolds Creek Experimental Watershed data have been published (Hanson 1982). Therefore, only equations for calculating the mean and standard deviation of the log transformed series from the statistical properties of the untransformed series will be presented in this report. The latest monthly generation procedures are discussed in the regional study which follows in this section of the report.

Markovic (1965) evaluated several statistical distributions and found that the annual precipitation series can be approximated by the log-normal two-parameter function (Chow 1954, 1964; Haan 1977). The equation adapted from Clarke (1973) for generating annual precipitation series using the log-normal distribution is

$$Y = \exp\,(u_{lnx} + \sigma_{lnx}y) \qquad [1.3]$$

where u_{lnx} is the average of the natural logs of the annual precipitation series, σ_{lnx} is the standard deviation of the natural logs of the annual precipitation series, and y is a pseudo-random normal deviate [N(0,1)].

The following two equations can be used to obtain estimates of u_{lnx} and σ_{lnx} which are required in equation [1.3] (Haan 1977)

Table 1.3.--Regression coefficients used to compute monthly precipitation [Y = a + bX; Y = monthly precipitation (in); X = elevation (ft); and a and b = coefficients].

	Downwind			Upwind		
	a	b	R^2	a	b	R^2
January	-6.18	.00198	.919	-4.72	.00134	.780
February	-4.45	.00128	.941	-5.24	.00127	.795
March	-3.62	.00116	.956	-3.19	.00090	.781
April	-2.56	.00093	.968	-1.69	.00060	.756
May	-1.53	.00057	.902	-1.50	.00048	.904
June	.16	.00031	.796	.27	.00024	.723
July	- .27	.00013	.745	- .27	.00013	.745
August	.24	.00012	.548	.24	.00012	.548
September	- .27	.00022	.762	- .24	.00017	.836
October	- .91	.00051	.893	-1.22	.00048	.803
November	-5.24	.00144	.943	-3.54	.00103	.848
December	-4.96	.00156	.948	-4.33	.00119	.834

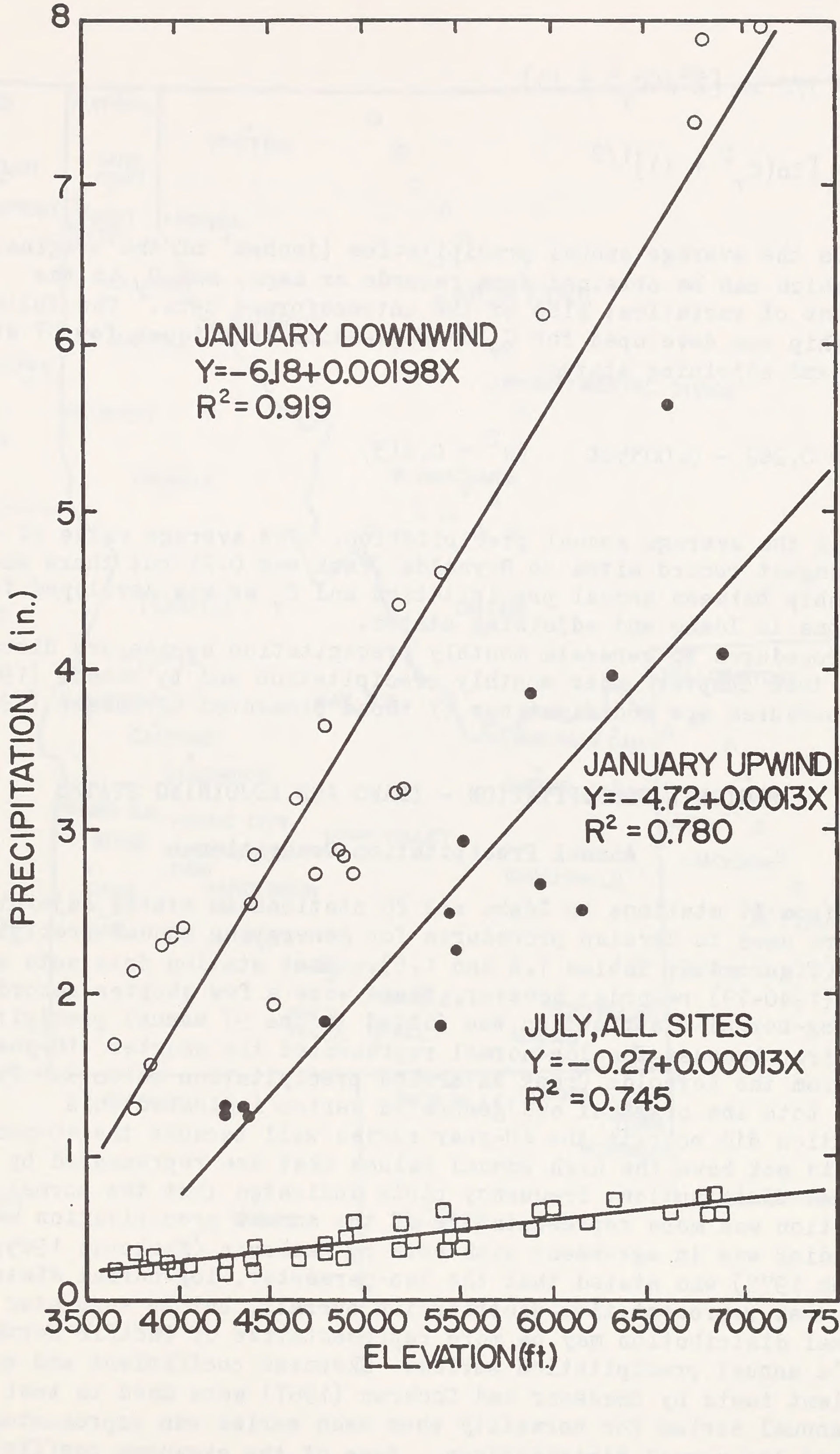


Figure 1.6.--Relationship between elevation and precipitation for January and July.

$$u_{\ln x} = 1/2 \ln [\bar{X}^2/(C_v^{\,2} + 1)] \quad [1.4]$$

$$\sigma_{\ln x} = [\ln(C_v^{\,2} + 1)]^{1/2} \quad [1.5]$$

where $\bar{X}$ is the average annual precipitation (inches) of the original data series, which can be obtained from records or maps, and C_v is the coefficient of variation; also of the untransformed data. The following relationship was developed for C_v by regression techniques for 57 stations in Idaho and adjoining states:

$$C_v = 0.262 - 0.00358X \qquad (R^2 = 0.613) \quad [1.6]$$

where X is the average annual precipitation. The average value of C_v for the 17 longest record sites on Reynolds Creek was 0.21 but there was no relationship between annual precipitation and C_v as was developed for the 57 stations in Idaho and adjoining states.

The procedures to generate monthly precipitation series are discussed later in this chapter under monthly precipitation and by Hanson (1982). These procedures are modifications of those presented by Hanson (1982).

REGIONAL PRECIPITATION - IDAHO AND ADJOINING STATES

Annual Precipitation Generation

Data from 31 stations in Idaho and 26 stations in states adjoining Idaho were used to develop procedures for generating annual precipitation amounts (Figure 1.7, Tables 1.4 and 1.5). Most station data sets were for 40-year (1940-79) records; however, there were a few shorter records.

The log-normal distribution was fitted to the 57 annual precipitation series first because the log-normal represented the shorter (18-year) series from the Reynolds Creek Watershed precipitation network. Frequency plots of both the original and generated series indicated this distribution did not fit the 40-year series well because the 40-year series did not have the high annual values that are represented by the log-normal distribution. Frequency plots indicated that the normal distribution was more representative of the annual precipitation series. This finding was in agreement with work by Markovic (Markovic 1965; Yevjevich 1972) who stated that the two-parameter, log-normal distribution was the most representative distribution overall, but he suggested that the normal distribution may be more representative of Pacific Northwest station's annual precipitation series. Skewness coefficient and excess coefficient tests by Snedecor and Cochran (1967) were used to test each of the 57 annual series for normality when each series was represented by the normal and log-normal distributions. None of the skewness coefficient values were significantly greater ($P>.01$) than would be expected if each of the series followed a normal distribution and only two stations in Idaho had excess coefficient values greater than expected. Three stations in Idaho and one outside of Idaho had skewness and excess coefficient values larger than expected if each series followed the log-normal

Figure 1.7.--Location of regional precipitation study stations.

Table 1.4.--The 31 Idaho precipitation stations.

Station Name	Station Number	Elevation (feet)	Annual Precipitation Average (inches)	Annual Precipitation Standard Deviation (inches)	Record Length
Anderson	100282	3882	20.12	4.74	1942-79
Arrowrock Dam	100448	3275	19.25	3.85	1940-79
Ashton	100470	5260	18.75	3.73	1940-79
Bliss	101002	3275	9.32	2.54	1940-79
Boise WSO	101022	2838	11.63	2.13	1940-79
Burley	101303	4146	9.71	2.14	1940-79
Cambridge	101408	2650	20.39	4.21	1940-79
Cascade	101514	4896	21.40	3.66	1944-79
Deadwood Dam	102385	5375	32.50	5.91	1940-74
Deer Flat Dam	102444	2510	9.86	2.07	1940-79
Dubois	102707	5452	11.86	2.44	1940-79
Hazelton	104140	4060	10.16	2.57	1940-79
Idaho City	104442	3965	24.49	4.51	1940-79
Idaho Falls CAA	104457	4730	9.43	2.37	1940-79
Island Park Dam	104598	6300	30.84	4.81	1943-79
Kellogg	104831	2290	30.42	4.91	1940-72
Kooskia	105011	1260	25.50	4.08	1940-79
Lifton	105275	5926	10.07	2.19	1940-79
Malad	105544	4600	14.69	3.21	1940-79
May	105685	5110	7.84	1.73	1940-79
McCall	105708	5025	28.12	3.96	1940-79
Montpelier	106053	5960	14.40	2.71	1940-79
Moscow, U of I	106152	2660	23.73	4.71	1940-79
Oakley	106542	4600	11.30	2.43	1940-79
Parma	106844	2215	10.92	2.98	1940-79
Porthill	107264	1800	20.48	3.61	1940-79
Priest River	107386	2380	32.71	4.71	1940-79
Saint Maries	108062	2220	30.00	4.95	1940-79
Sandpoint	108137	2100	33.01	4.97	1940-79
Sun Valley	108906	5980	17.36	3.93	1941-72
Twin Falls	109294	3690	9.48	2.37	1940-73

Table 1.5.--The 26 stations adjoining Idaho.

Station Name	Station Number	Elevation (feet)	Annual Precipitation Average (inches)	Annual Precipitation Standard Deviation (inches)	Record Length
Montana					
Dillon	242404	5218	9.41	1.85	1940-79
East Anaconda	242604	5511	13.81	3.23	1940-79
Fortine	243139	3000	17.27	3.91	1940-79
Heron	244084	2240	34.21	5.50	1940-79
Superior	248043	2710	17.36	3.17	1940-79
Nevada					
Owyhee	265869	5396	14.33	2.89	1940-79
Wells	268988	5650	10.45	2.73	1940-79
Oregon					
Cove	351926	3115	22.89	4.07	1940-79
Danner	352135	4397	11.93	2.63	1940-79
Malheur	355160	2240	9.72	2.15	1943-80
Utah					
Laketown	424856	5988	11.49	2.60	1940-79
Logan	425186	4784	17.68	3.27	1940-79
Park Valley	426658	5571	10.75	2.48	1940-79
Woodruff	429595	6315	9.04	2.02	1940-79
Washington					
Chewelah	451395	1675	20.21	3.60	1940-79
Colfax	451586	1955	20.48	4.12	1940-79
Dayton	452030	1557	19.21	3.92	1940-79
Hatton	453546	1430	10.17	2.28	1940-79
Kennewick	454154	392	7.73	2.10	1940-79
Laurier	454549	1644	19.42	3.16	1940-79
Newport	455844	2135	27.63	4.34	1940-79
Odessa	456039	1540	10.37	2.76	1940-79
Wyoming					
Alta	480140	6430	20.62	4.98	1949-77
Afton	484095	6210	18.32	3.10	1937-76
Jackson	484910	6230	15.56	2.92	1938-77
Yellowstone Pk.	489905	6200	15.96	3.02	1939-76
					1978-79

distribution. There was no apparent relationship between positive or negative skew and mean annual amount or location within the region. These tests suggested that the normal distribution could be used to generate annual precipitation series. The following equation was used to generate annual series (Clarke 1973):

$$Y_a = (\bar{X}_a + \sigma_a y) \qquad [1.7]$$

where Y_a is the generated annual precipitation, $\bar{X}_a$ is the mean annual precipitation, σ_a is the standard deviation of the annual series, and y is a pseudo-random normal deviate [N(0,1)].

Equation [1.7] was used to generate 50-year series for each of the 57 stations by using the mean and standard deviation computed for each site. Table 1.6 is a summary of 50-year simulations for 13 stations that have widely differing annual precipitation amounts and are located in different geographical areas. As can be seen, the measured and simulated average annual amounts were all within five percent, and the measured and all but four simulated standard deviations were within five percent. The range of values that were simulated were also very close to the measured values. The Kolmogorov-Smirnov test (Siegal 1956) for goodness-of-fit showed that none of the measured and simulated distributions were significantly different ($P < .05$).

The following linear relationship was developed for the relationship between average annual precipitation and the standard deviation of each station's annual series so that only the annual mean is needed for generating an annual series. The relationship is:

$$\sigma_a = 1.12 + 0.128\bar{X}_a \quad (R^2 = 0.868) \quad (F = 360.20) \quad (n = 57). \qquad [1.8]$$

As can be seen from Figure 1.8, there was a good relationship between average annual precipitation and the associated standard deviations. Each of the standard deviation values was plotted on maps and no relationship could be discerned between standard deviation and region or elevation, so all of the data were grouped to develop equation [1.8].

The following annual precipitation generation procedure, based on the 57 station record for Idaho and adjoining states, is as follows:

1. Compute the mean annual precipitation ($\bar{X}_a$) for the location in question from climatic records, isohyetal maps, etc.;

2. Compute the standard deviation (σ_a) from equation [1.8];

3. Obtain as many values of y as is required from a table of pseudo-random normal deviates [N(0,1)] or from a computer program for generating these values; and

4. Use equation [1.7] to compute the synthetic annual precipitation series.

Table 1.6.--A summary of 50-year simulations of average annual precipitation at 13 sites in or near Idaho.

Site		Average Precipitation (inches)	Standard Deviation (inches)	Range of Annual Values (inches)	
Arrowrock Dam, ID	Measured[1/]	19.25	3.85	29.29	12.32
	Simulated	18.34	3.40	26.69	11.11
Boise WSO, ID	Measured	11.62	2.13	15.77	6.64
	Simulated	11.62	2.18	15.61	4.19
Deadwood Dam, ID	Measured	32.50	5.91	49.82	22.37
	Simulated	33.79	6.04	45.45	16.78
Dubois, ID	Measured	11.86	2.44	17.62	7.81
	Simulated	11.64	2.51	16.80	6.64
Hazelton, ID	Measured	10.16	2.57	15.55	4.30
	Simulated	10.30	2.75	16.84	4.68
Kooskia, ID	Measured	25.50	4.08	35.54	16.80
	Simulated	25.63	4.21	37.43	17.73
Montpelier, ID	Measured	14.40	2.71	20.82	8.55
	Simulated	14.02	2.85	20.22	9.32
Saint Maries, ID	Measured	30.00	4.95	40.21	18.32
	Simulated	30.90	5.61	41.50	19.71
Superior, MT	Measured	17.36	3.17	23.42	10.75
	Simulated	17.60	3.07	25.14	9.91
Owyhee, NV	Measured	14.33	2.89	21.13	8.53
	Simulated	14.14	2.80	20.83	7.51
Danner, OR	Measured	11.93	2.63	18.31	6.66
	Simulated	12.47	2.00	18.29	7.18
Colfax, WA	Measured	20.48	4.12	30.84	13.27
	Simulated	21.05	3.04	27.82	13.68
Kennewick, WA	Measured	7.73	2.10	12.90	3.78
	Simulated	7.99	2.19	13.62	3.31
Average	Measured	17.47			
	Simulated	17.65			

1/ The measured values were based on 40-year records except the Deadwood Dam record which was 35 years.

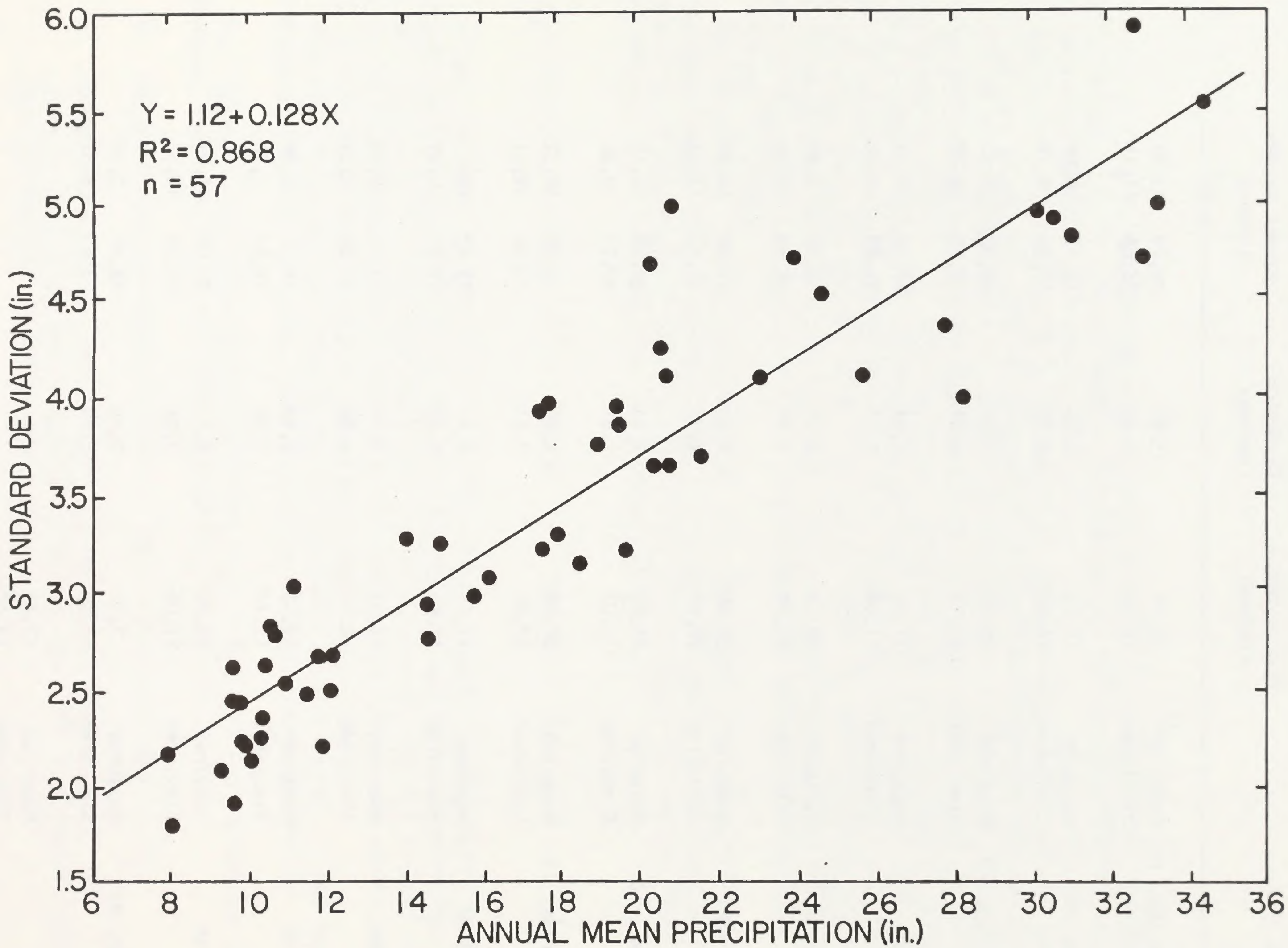


Figure 1.8.--Relationship between mean annual precipitation and the standard deviation.

Summary of Average Annual Precipitation Generation Study

The log-normal distribution represented the annual precipitation series on the Reynolds Creek Experimental Watershed and the normal distribution represented the 57, 40-year stations in Idaho and adjoining states. The reason for this was probably because of the shorter 18-year record used for Reynolds Creek Experimental Watershed. Analyses of the now available 21-year record shows that the normal distribution may represent the gage sites on Reynolds Creek as well as the log-normal distribution. The reason for this is because, with the shorter record, some of the larger values were quite high relative to the mean; but as a longer record is obtained, the high values tend to be limited at about the same amount above the average as the low values are below the average, which is indicative of a nonskewed normally distributed series. These findings are good from a user's standpoint because the normal distribution requires the least information and is, thus, the easiest to use for generating annual precipitation series.

Monthly Precipitation Generation

The 57 stations shown in Tables 1.4 and 1.5 were used for the monthly precipitation generation study. The fraction of years with precipitation from each monthly series (α) is listed in Tables 1.7 and 1.8. The values of α for January and July are plotted in Figures 1.9 and 1.10 to illustrate the climatic differences across the region. As can be seen, all values of α for January are 1.0, except in southwestern Montana and west central Wyoming. This pattern changes in July when α is 1.0 in western Montana and western Wyoming and decreased to about 0.75 in southwest Idaho and eastern Oregon. Maps of each monthly value of α can be drawn, but α is very site-dependent, therefore, all of the data were listed in Tables 1.7 and 1.8 so that when values of α are needed for generating monthly precipitation series, all information is available for selecting the correct value.

Analyses of monthly records from the 57 stations showed that the cube-root-normal distribution (Kendall 1960; Stidd 1953, 1970) was the preferred distribution to use to represent monthly series, rather than either the normal or log-normal distributions (Table 1.9).

Several of the station series during the winter months of January, November, and December, and the summer months of May and August were not represented by the cube-root-normal distribution (seven or fewer of the 57 stations). There was no geographical pattern associated with the stations where the cube-root-series did not represent the data, which indicated that the cube-root-normal distribution could be used to represent monthly precipitation series. These analyses indicated that the skewness coefficient test was a more sensitive test of normality than the excess coefficient test for monthly precipitation series.

The following equation was used to generate monthly transformed series:

$$V = (\bar{W}_m - \sigma_m y) \qquad [1.9]$$

where V is each transformed generated monthly value, $\bar{W}_m$ is the mean of the original transformed series, and σ_m is the standard deviation of the

Table 1.7.--Values of α[1/] for Idaho climatological stations.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anderson	1.000	1.000	1.000	1.000	1.000	.974	.868	.789	.868	.974	.974	1.000
Arrowrock	1.000	1.000	1.000	1.000	1.000	1.000	.775	.775	.925	.950	1.000	1.000
Ashton	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	.950	.950	.975	1.000
Bliss	1.000	1.000	1.000	1.000	.950	.950	.700	.675	.775	.950	.975	.975
Boise	1.000	1.000	1.000	1.000	1.000	1.000	.800	.825	.950	.950	1.000	1.000
Burley	1.000	.975	1.000	1.000	.975	1.000	.875	.825	.850	.925	1.000	.975
Cambridge	1.000	1.000	1.000	1.000	1.000	1.000	.700	.800	.900	.975	1.000	1.000
Cascade	1.000	1.000	1.000	1.000	1.000	1.000	.833	.917	.944	.972	1.000	1.000
Deadwood	1.000	1.000	1.000	1.000	1.000	1.000	.971	.914	.971	1.000	1.000	1.000
Deer Flat	1.000	1.000	.975	.975	.975	1.000	.700	.750	.875	.950	1.000	1.000
Dubois	1.000	1.000	.975	1.000	1.000	1.000	1.000	1.000	.925	.950	.975	.975
Hazelton	1.000	1.000	1.000	1.000	.975	1.000	.850	.875	.850	.900	1.000	.975
Idaho City	1.000	1.000	1.000	1.000	.975	.975	.750	.775	.900	.950	1.000	1.000
Idaho Falls	1.000	1.000	.975	1.000	1.000	1.000	.950	.950	.950	.925	.975	1.000
Island	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.973	.973	1.000	1.000
Kellogg	1.000	1.000	1.000	1.000	1.000	1.000	.947	.974	1.000	1.000	1.000	1.000
Kooskia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.875	1.000	1.000	1.000	1.000
Lifton	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	.925	1.000	.975
Malad	1.000	1.000	1.000	1.000	1.000	1.000	.950	.950	.925	.925	1.000	.975
May	1.000	.900	.950	1.000	1.000	1.000	1.000	.950	1.000	.900	.975	.975
McCall	1.000	1.000	1.000	1.000	1.000	1.000	.925	.925	.975	1.000	1.000	1.000
Montpelier	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	.950	1.000	1.000
Moscow	1.000	1.000	1.000	1.000	1.000	1.000	.900	.925	.975	1.000	1.000	1.000
Oakley	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.950	.900	.950	1.000	1.000
Parma	1.000	1.000	1.000	.950	.975	1.000	.775	.825	.875	.950	1.000	1.000
Porthill	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.950	1.000	1.000	1.000	1.000
Priest	1.000	1.000	1.000	1.000	1.000	1.000	.950	.975	1.000	1.000	1.000	1.000
Saint Maries	1.000	1.000	1.000	1.000	1.000	1.000	.900	.975	1.000	1.000	1.000	1.000
Sandpoint	1.000	1.000	1.000	1.000	1.000	1.000	.950	.950	.975	.975	1.000	1.000
Sun Valley	1.000	1.000	1.000	1.000	1.000	1.000	.969	.969	.959	.937	.969	1.000
Twin Falls	1.000	1.000	1.000	1.000	.971	1.000	.853	.794	.882	.971	1.000	1.000

[1/] α = number of years with precipitation during the month divided by the total number of years in the series.

Table 1.8.--Values of α[1/] for precipitation stations in states adjoining Idaho.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Montana												
Dillon	.975	.950	.975	1.000	1.000	1.000	1.000	.975	1.000	.950	.975	.975
E. Anaconda	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	1.000
Fortine	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	1.000	1.000	1.000
Heron	1.000	1.000	1.000	1.000	1.000	1.000	.900	.950	1.000	1.000	1.000	1.000
Superior	1.000	1.000	1.000	.975	1.000	1.000	.975	.925	1.000	1.000	1.000	1.000
Nevada												
Owhyee	1.000	1.000	1.000	1.000	.950	1.000	.875	.775	.900	.950	1.000	1.000
Wells	1.000	1.000	1.000	1.000	1.000	1.000	.850	.925	.900	.975	.975	1.000
Oregon												
Cove	1.000	1.000	1.000	1.000	1.000	1.000	.925	.900	.975	1.000	1.000	1.000
Danner	1.000	1.000	1.000	1.000.	1.000	.975	.775	.800	.850	.950	1.000	1.000
Malheur	1.000	1.000	1.000	1.000	1.000	.974	.737	.816	.868	.974	1.000	1.000
Utah												
Laketown	1.000	1.000	1.000	.950	.975	1.000	1.000	.975	1.000	.950	.950	.975
Logan	1.000	1.000	1.000	1.000	1.000	1.000	.950	.950	1.000	.950	1.000	1.000
Park Valley	1.000	1.000	.975	1.000	1.000	.975	.900	.975	.900	.925	.975	.975
Woodruff	.975	1.000	1.000	.975	1.000	1.000	1.000	.975	1.000	.975	1.000	.975
Washington												
Chewlah	1.000	1.000	1.000	1.000	1.000	1.000	.975	.950	.975	.975	1.000	1.000
Colfax	1.000	1.000	1.000	1.000	1.000	1.000	.850	.875	.975	1.000	1.000	1.000
Dayton	1.000	1.000	1.000	1.000	1.000	1.000	.800	.850	1.000	1.000	1.000	1.000
Hutton	1.000	1.000	1.000	1.000	1.000	1.000	.800	.825	.950	1.000	1.000	1.000
Kennewick	1.000	.975	1.000	.900	1.000	1.000	.675	.775	.900	.975	1.000	1.000
Laurier	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	1.000	1.000	1.000	1.000
Newport	1.000	1.000	1.000	1.000	1.000	1.000	.950	.950	.975	1.000	1.000	1.000
Odessa	.975	1.000	1.000	1.000	1.000	1.000	.875	.800	.900	1.000	1.000	1.000
Wyoming												
Alta	.967	1.000	1.000	1.000	1.000	1.000	.967	1.000	.967	.967	.967	1.000
Afton	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.950	.950	.975	.975	1.000
Jackson	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	.975	.975	.975	1.000
Yellowstone	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.975	.975	1.000	1.000

[1/] α = number of years with precipitation during the month divided by the total number of years in the series.

Figure 1.9.--Alpha (α) for January.

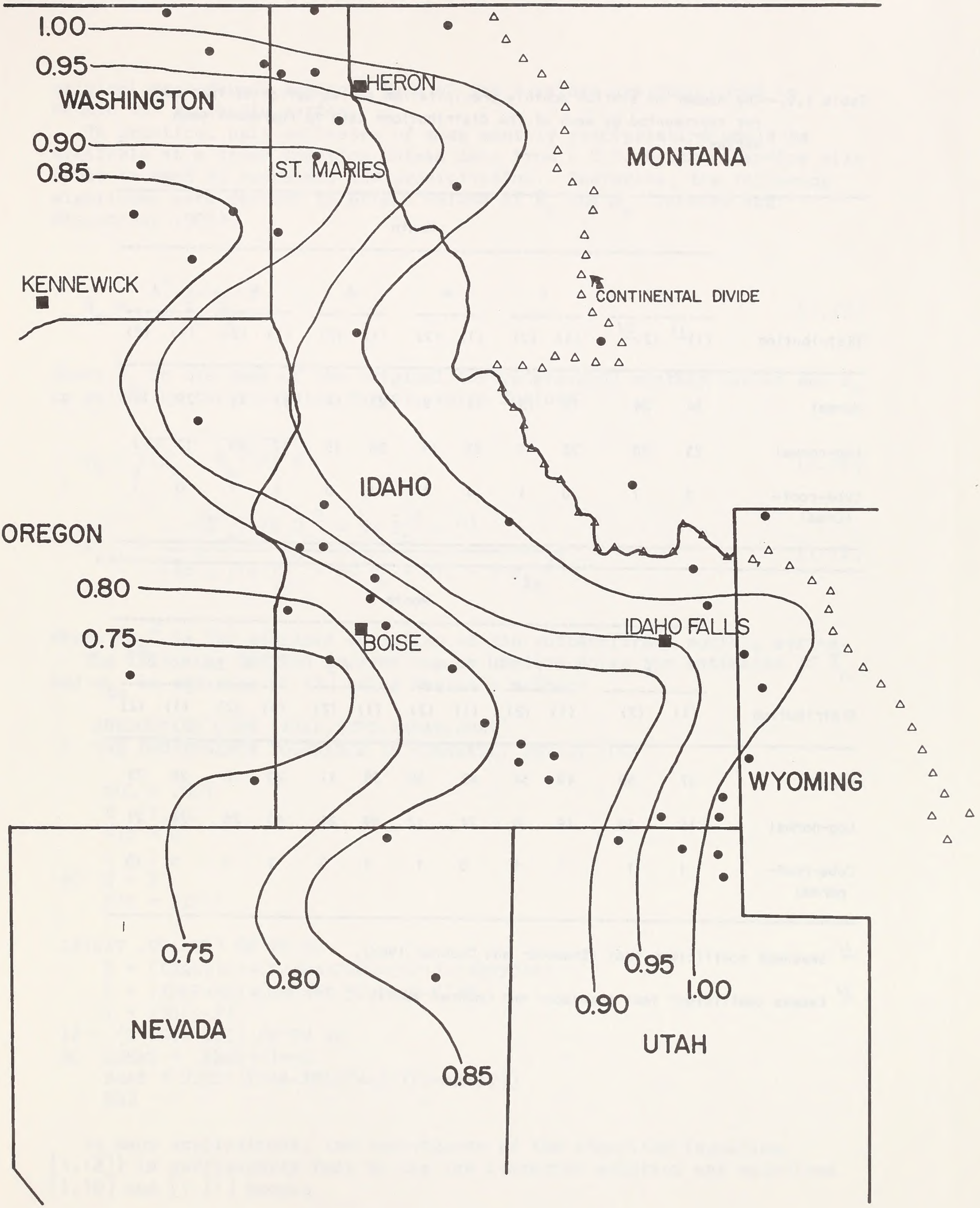


Figure 1.10.--Alpha (α) for July.

Table 1.9.--The number of station monthly precipitation series out of 57 that were not represented by each of the distributions used to represent each series.

	Month											
	J		F		M		A		M		J	
Distribution	(1)1/	(2)2/	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Normal	34	24	18	13	14	9	23	14	37	19	29	11
Log-normal	23	20	22	17	27	19	26	15	17	13	17	7
Cube-root-normal	3	7	0	1	4	5	1	0	1	1	0	1

	Month											
	J		F		M		A		M		J	
Distribution	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Normal	47	30	49	34	42	30	38	17	20	12	28	23
Log-normal	16	10	19	8	24	12	39	24	40	26	24	21
Cube-root-normal	1	1	5	5	0	1	1	0	7	4	5	10

1/ Skewness coefficient test (Snedecor and Cochran 1967).

2/ Excess coefficient test (Snedecor and Cochran 1967).

original transformed series. Each of the V values are then cubed to obtain the synthetic series.

In practice, only estimates of mean monthly precipitation would be available at a study location unless data from a U.S. Weather Service site could be used to represent the precipitation. Therefore, the following algorithms were derived to obtain values of $\bar{W}_m$ and σ_m (Potratz and Steinhorst 1983):

$$\bar{W}_m = \sqrt[3]{\bar{X}_m P_n} \qquad [1.10]$$

where $\bar{X}_m$ is the mean of the original (untransformed) monthly series and P_n is solved by the recursion formula which follows

$$\sigma_m = \sqrt{(\bar{X}_m - \bar{W}_m^{\,3})/3\,\bar{W}} \qquad [1.11]$$

$$P_{n+1} = \frac{(\bar{X}^2_m)\,(8\,P_n^{\,3} - 30\,P_n^{\,2} - 5)}{(\bar{X}m^2)\,(12\,P_n^{\,2} - 60\,P_n + 21) - 9\,\sigma_{Xm}^{\,2}} \qquad [1.12]$$

where $\sigma_{Xm}^{\,2}$ is the standard deviation of the untransformed monthly series.

The following FORTRAN program can be used to solve for estimates of $\bar{X}_m$ and σ_{Xm} in equation [1.12] using Newton's method:

```
   SUBROUTINE CUBE (XBAR,XSTD,AMHAT,SHAT)
C  THE CONVERGENCE TOLERANCE IS CURRENTLY SET AT .001

    TOL = .001
    E = 1./3.
    NIT = 0
    P = 1
40  Q = P
    NIT = NIT+1

IF(NIT .GT. 25) GØ TØ 50
    D = (XBAR**2)*(12*P**2-60*P+21)-9*XSTD**2
    P = (XBAR**2)*(8*P**3-30*P**2-5)/D
    T = ABS(Q-P)
IF = (T .GT. TOL) GØ TØ 40
50  AMHAT = (XBAR*P)**E
    SHAT = SQRT((XBAR-AMHAT**3)/(3*AMHAT))
    END
```

In many applications, the convergence of the algorithm (equation [1.12]) is sufficiently fast to use the iteration solution and equations [1.10] and [1.11] become

$$P_1 = \frac{\bar{X}_m^{\,2}}{\bar{X}_m^{\,2} + \frac{\sigma X_m^{\,2}}{3}}$$

$$\bar{W}_{m1} = \bar{X}_m \left(\bar{X}_m^{\,2} + \frac{(\sigma_{Xm})^2}{3}\right)^{-1/3} \qquad [1.13]$$

and

$$\sigma_{m1} = \frac{\sigma_{Xm}}{3}\left(\bar{X}_m^{\,2} + \frac{\sigma_{XM}^{\,2}}{3}\right)^{-1/3} \qquad [1.14]$$

The following linear relationships were developed between average monthly precipitation and the standard deviation of each station's monthly series, so that only monthly mean values are needed for generating monthly series. The relationships are:

November - June

$$\sigma_{Xm} = 0.186 + 0.456\ \bar{X}_m \quad (R^2 = 0.851) \quad (N = 456) \qquad [1.15]$$

July and October

$$\sigma_{Xm} = 0.125 + 0.636\ \bar{X}_m \quad (R^2 = 0.940) \quad (N = 114) \qquad [1.16]$$

August and September

$$\sigma_{X}m = 0.345 + 0.517\ \bar{X}_m \quad (R^2 = 0.738) \quad (N = 114) \qquad [1.17]$$

where σ_{Xm} = monthly standard deviation and
X = mean monthly precipitation.

A summary of 50-year simulations for the locations--Boise, Idaho, Saint Maries, Idaho, Heron, Montana, and Kennewick, Washington, is presented in Tables 1.10 through 1.13. The Kolmogrov-Smirnov test (Siegal 1956) for goodness-of-fit indicated that the measured and simulated cumulative distributions were not different at the five percent level for any of the months at the four sites. The simulated values of standard deviation were also very close to the measured values.

The following procedure can be used to generate synthetic monthly series:

1. Determine the value of α from Tables 1.7 and 1.8;

Table 1.10.--A summary of a 50-year simulation of monthly precipitation (in) at Boise WSO, Idaho.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly	Measured	1.49	1.16	1.08	1.16	1.15	.99	.21	.35	.52	.84	1.32	1.35
Average Monthly excluding years with no precipitation	Measured	1.49	1.16	1.08	1.16	1.15	.99	.27	.42	.55	.89	1.32	1.35
	Simulated	1.61	1.07	1.22	1.13	.96	.70	.25	.36	.63	.89	1.36	1.34
Standard Deviation excluding years with no precipitation	Measured	.87	.61	.64	.76	.87	.78	.28	.52	.60	.59	.62	.77
	Simulated	1.03	.58	.86	.94	.59	.64	.28	.44	.76	.57	.71	.67
Range	Measured												
	High	3.87	2.62	2.27	3.04	4.00	3.41	1.15	2.37	2.54	2.25	2.44	3.19
	Low	.12	0.19	0.18	0.09	0.09	0.01	.00	.00	.00	.00	.14	.09
	Simulated												
	High	5.24	2.41	3.92	4.49	3.01	3.41	1.25	1.66	4.05	2.65	3.30	2.90
	Low	.32	.27	0.15	.06	.02	.03	.00	.00	.00	.00	.29	0.18
1/	Measured	1.00	1.00	1.00	1.00	1.00	1.00	.80	.83	.95	.95	1.00	1.00
	Simulated	1.00	1.00	1.00	1.00	1.00	1.00	.78	.84	.98	.98	1.00	1.00

1/ Number of months in series with precipitation divided by total number of months in series.

Table 1.11.--A summary of a 50-year simulation of monthly precipitation (in) at Saint Maries, Idaho.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly	Measured	4.16	3.03	2.67	2.17	2.23	2.17	.84	1.12	1.44	2.40	3.72	4.05
Average Monthly excluding years with no precipitation	Measured	4.16	3.03	2.67	2.17	2.23	2.17	.93	1.15	1.44	2.40	3.72	4.05
	Simulated	4.20	2.88	2.62	2.19	2.08	2.04	.87	1.14	1.31	2.16	3.66	3.92
Standard Deviation excluding years with no precipitation	Measured	2.33	1.51	1.12	.95	1.26	1.07	.82	.99	1.10	1.60	1.77	1.55
	Simulated	2.49	1.27	1.14	1.28	1.00	.97	.74	1.07	.90	1.93	1.85	1.21
Range	Measured												
	High	9.92	6.71	5.27	3.93	6.48	5.07	3.75	4.28	4.33	6.31	8.61	8.62
	Low	.65	.85	.69	.65	.74	.57	.00	.00	.07	.03	.48	1.59
	Simulated												
	High	10.90	5.79	6.20	6.44	4.73	3.94	2.56	3.96	3.79	8.02	10.67	6.71
	Low	1.30	.48	.70	.31	.27	.21	.00	.00	.03	.22	.88	1.30
1/	Measured	1.00	1.00	1.00	1.00	1.00	1.00	.90	.98	1.00	1.00	1.00	1.00
	Simulated	1.00	1.00	1.00	1.00	1.00	1.00	.78	.96	1.00	1.00	1.00	1.00

1/ Number of months in series with precipitation divided by total number of months in series.

Table 1.12.--A summary of a 50-year simulation of monthly precipitation (in) at Heron, Montana.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly	Measured	4.66	3.61	2.73	2.01	2.44	2.72	.89	1.52	1.93	2.83	4.26	4.61
Average Monthly excluding years with no precipitation	Measured	4.66	3.61	2.73	2.01	2.44	2.72	.99	1.60	1.93	2.83	4.26	4.61
	Simulated	5.01	3.36	2.65	2.09	2.87	2.48	1.03	1.72	2.01	3.11	4.29	4.82
Standard Deviation excluding years with no precipitation	Measured	2.41	1.69	1.19	.93	1.36	1.30	.71	1.42	1.66	2.03	2.26	1.53
	Simulated	2.30	1.72	1.08	.90	1.29	1.14	.75	1.37	1.74	2.36	2.41	1.93
Range	Measured												
	High	12.27	7.00	6.79	5.10	6.01	5.30	2.78	7.22	7.94	8.47	8.68	7.80
	Low	1.56	.88	.38	.21	.82	.50	.00	.00	.20	.03	.54	1.74
	Simulated												
	High	11.65	7.20	5.58	4.39	6.10	5.04	3.12	6.09	9.73	13.45	10.98	11.21
	Low	1.32	.58	.68	.73	.49	.47	.00	.00	0.04	0.05	.51	1.17
1/	Measured	1.00	1.00	1.00	1.00	1.00	1.00	.90	.95	1.00	1.00	1.00	1.00
	Simulated	1.00	1.00	1.00	1.00	1.00	1.00	.98	.94	1.00	1.00	1.00	1.00

1/ Number of months in series with precipitation divided by total number of months in series.

Table 1.13.--A summary of a 50-year simulation of monthly precipitation (in) at Kennewick, Washington.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly	Measured	1.09	.75	.54	.48	.60	.55	.19	.35	.33	.67	1.05	1.13
Average Monthly excluding years with no precipitation	Measured	1.09	.76	.54	.53	.60	.55	.28	.45	.37	.68	1.05	1.13
	Simulated	1.18	.65	.53	.56	.61	.57	.23	.36	.32	.67	1.16	1.06
Standard Deviation excluding years with no precipitation	Measured	.79	.62	.40	.42	.54	.50	.31	.45	.34	.70	.68	.72
	Simulated	.68	.44	.44	.49	.45	.46	.20	.34	.34	.61	.59	.70
Range	Measured												
	High	3.87	3.57	1.77	1.85	2.29	2.27	1.38	1.67	1.49	3.07	3.04	3.47
	Low	.18	.00	.01	.00	.02	.01	.00	.00	.00	.00	.09	.25
	Simulated												
	High	3.54	1.62	1.93	1.59	1.81	2.20	.94	1.45	1.60	2.34	2.61	3.09
	Low	0.21	.01	.02	.01	.01	.02	.00	.00	.00	.00	.13	.21
1/	Measured	1.00	.97	1.00	.90	1.00	1.00	.68	.77	.90	.97	1.00	1.00
	Simulated	1.00	1.00	1.00	.84	1.00	1.00	.76	.82	.90	.98	1.00	1.00

1/ Number of months in series with precipitation divided by total number of months in series.

2. Obtain the mean monthly precipitation for the location from maps or other aids;

3. Compute $\bar{W}_m$ from equation [1.10] or [1.13];

4. Compute σ_m from equation [1.11] or [1.14];

5. Obtain a value from a uniform distribution to determine if the value in the series is zero by comparing with α; if equal to or greater than α, value is zero.

6. Obtain value of y from tables of pseudo-random normal deviates [N(0,1)] or from a computer program;

7. Compute the transformed synthetic value using equation [1.9];

8. Repeat steps 5 through 7 until the required number of values is in the series; and

9. Compute the untransformed series by cubing the values obtained in step 8 for the percent of years in the series that have precipitation as determined from the value of α.

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Chapter 2

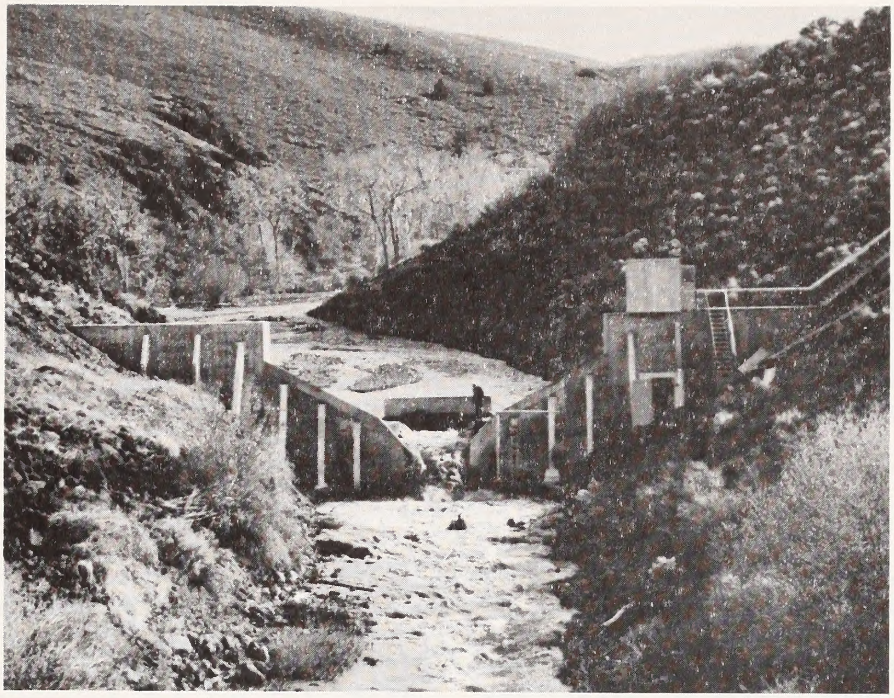
STREAMFLOW AND RUNOFF

CLIFTON W. JOHNSON, Research Hydraulic Engineer

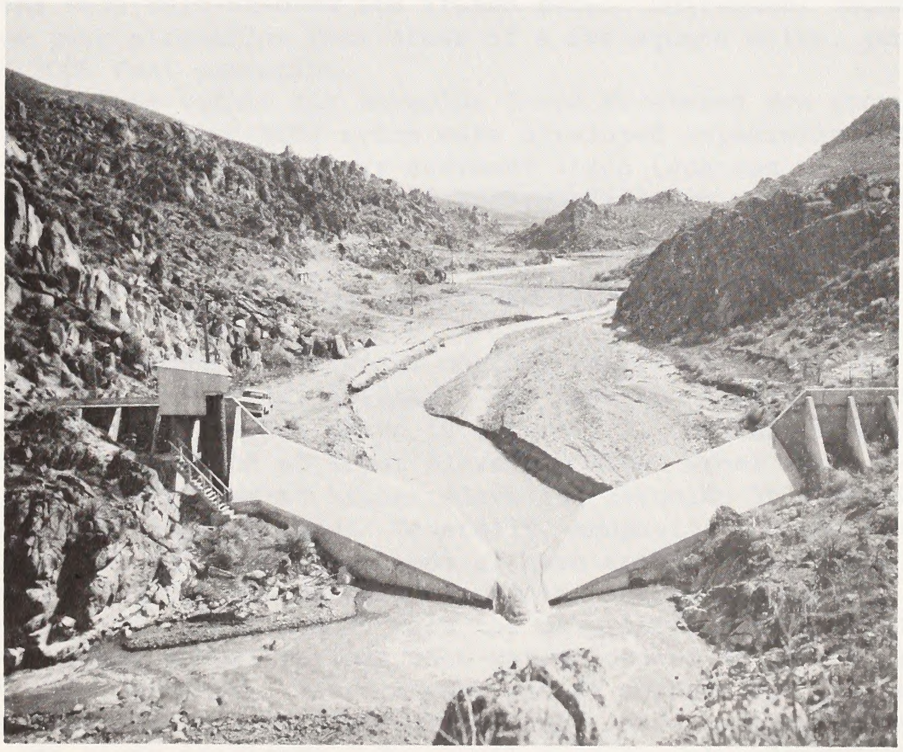
Chapter 2

STREAMFLOW AND RUNOFF

CONTENTS



Tollgate Drop Box Weir



Reynolds Creek Outlet Weir

INTRODUCTION

One of the major purposes in establishing the Reynolds Creek Experimental Watershed was to obtain accurate streamflow records from a representative sagebrush rangeland watershed in the Northwest as part of extensive hydrologic investigations (Robins et al. 1965). Weir modeling and construction began in 1960 and continued for about 10 years. Standard weirs and flumes were used on some smaller streams, but weirs on major streams were modeled and precalibrated in the hydraulic laboratory.

STREAMFLOW STATIONS

Reynolds Creek is a north-flowing tributary of the Snake River, with the experimental watershed outlet about 10 miles upstream from the confluence. Long-term stations are on continuously flowing streams, except intermittent Lower Sheep Creek, Table 2.1. Short-term stations have been operated for special studies, and length of record varies. Water is diverted from Reynolds Creek between the Tollgate and Outlet stations for spring and summer irrigation of nearly 2000 acres of hay, pasture, and grain crops in Reynolds Valley. Also, small areas are irrigated upstream from Macks Creek and Salmon Creek streamflow measuring stations. Streamflow at most stations is sustained by snowmelt and low summer baseflow from groundwater. The greatest floods have been caused by winter storms with rain-on-snow and frozen soil. Infrequent thunderstorms also produce peak streamflow from areas of a few square miles, generally below about 5000 feet elevation.

Station locations within the Reynolds Creek Watershed are shown in Figure 2.1. Drop-box and SCOV weirs were developed especially for Reynolds Creek stations with heavy sediment loads (Johnson et al. 1966). Drainage areas and elevation range of watersheds range widely, Table 2.1.

STREAMFLOW AND RUNOFF PATTERNS

The average, maximum, and minimum monthly runoff in inches for Reynolds Outlet, Macks Creek, Reynolds Tollgate, and Reynolds Mountain East watershed runoff stations are shown in Figure 2.2. Maximum monthly streamflows occur in March at lower elevation Macks Creek and Reynolds Outlet stations and in May at higher elevation Reynolds Tollgate and Reynolds Mountain East stations. Generally, snowmelt accounts for about 50 percent, 65 percent, and 85 percent of mean annual runoff from Macks Creek, Reynolds Outlet, and Reynolds Mountain East watersheds, respectively. Mean annual runoff from the watershed above Tollgate is about equal to mean annual maximum snow water content at snow courses above 6000 feet elevation. Year-to-year runoff amounts for the periods of record from Reynolds Outlet, Reynolds Tollgate, and Reynolds Mountain East watersheds are shown in Figure 2.3. April through July streamflow at

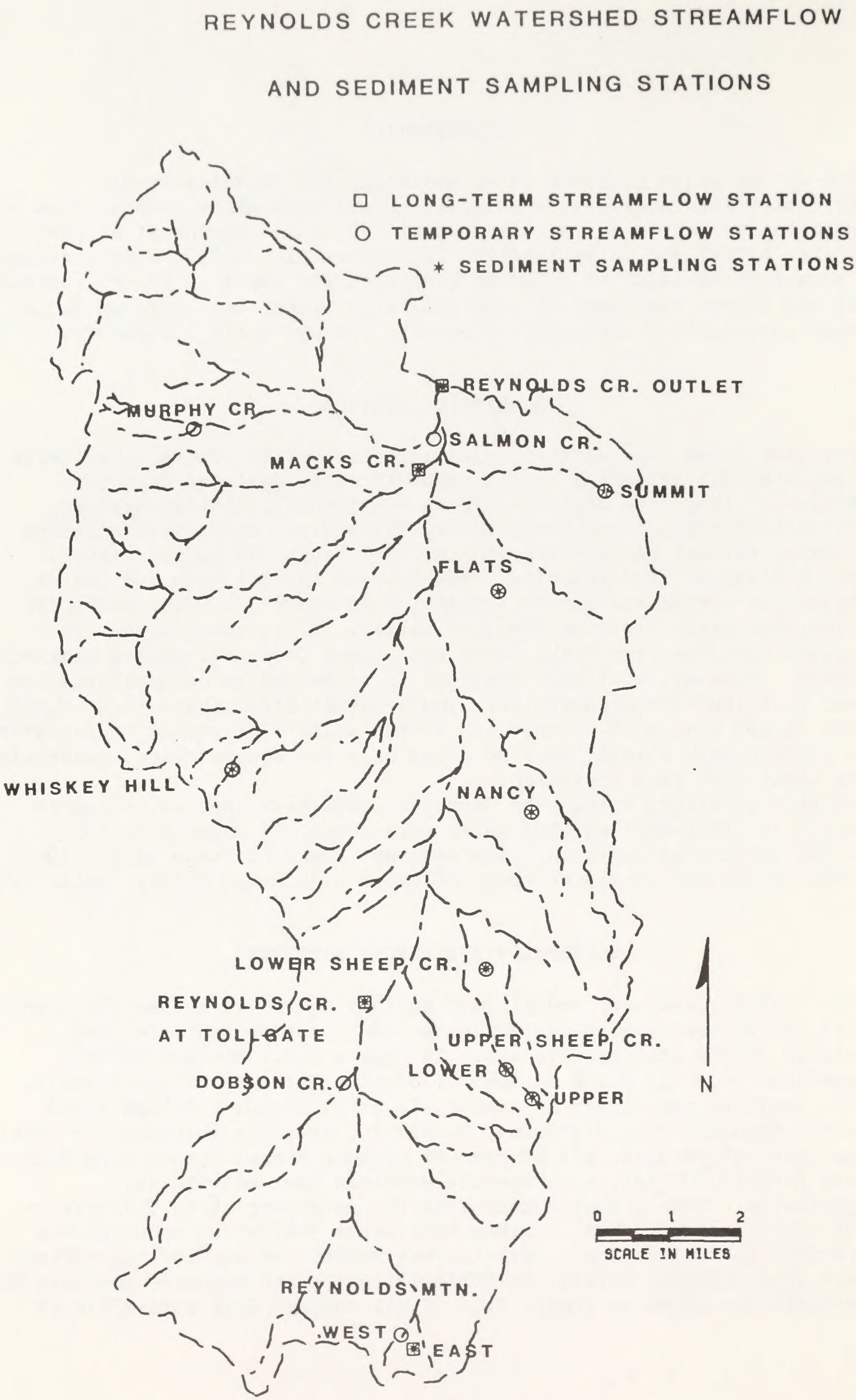


Figure 2.1.--Streamflow measuring stations on the Reynolds Creek Experimental Watershed.

Table 2.1. Streamflow stations on the Reynolds Creek Experimental Watershed (see Figure 2.1.).

Station Measuring name	Location number	Record began	Area, acres	Elevation range, feet	device
Long-term stations:					
Reynolds Cr. Outlet	036068	1963	57,754	3600-7300	SCOV Weir
Macks Creek	046084	1965	7,846	3730-6200	Drop-box Weir
Reynolds Cr. Tollgate	116083	1966	13,453	4600-7300	Drop-box Weir
Lower Sheep Creek	117066	1966	33	5210-5440	Drop-box Weir
Reynolds Mtn. East	166076	1963	100	6620-7030	V-notch Weir
Short-term stations:					
Murphy Creek	043004	1967	306	4550-6000	Drop-box Weir
Salmon Creek	046017	1964	8,990	3670-6300	Drop-box Weir
Summit Basin	048077	1965	205	4150-5000	Drop-box Weir
Flats Micro	057096	1971	2.24	3880-3910	V-notch Weir
Nancy Micro	098097	1971	3.10	4640-4680	V-notch Weir
Dobson Creek	135017	1973	3,482	4840-7300	Parshall Flume
Upper Sheep Lower	138012	1970	63.4	6000-6520	Drop-box Weir
Upper Sheep Upper	138034	1970	15.7	6320-6640	Drop-box Weir
Reynolds Mtn. West	166074	1963	126	6620-7000	V-notch Weir

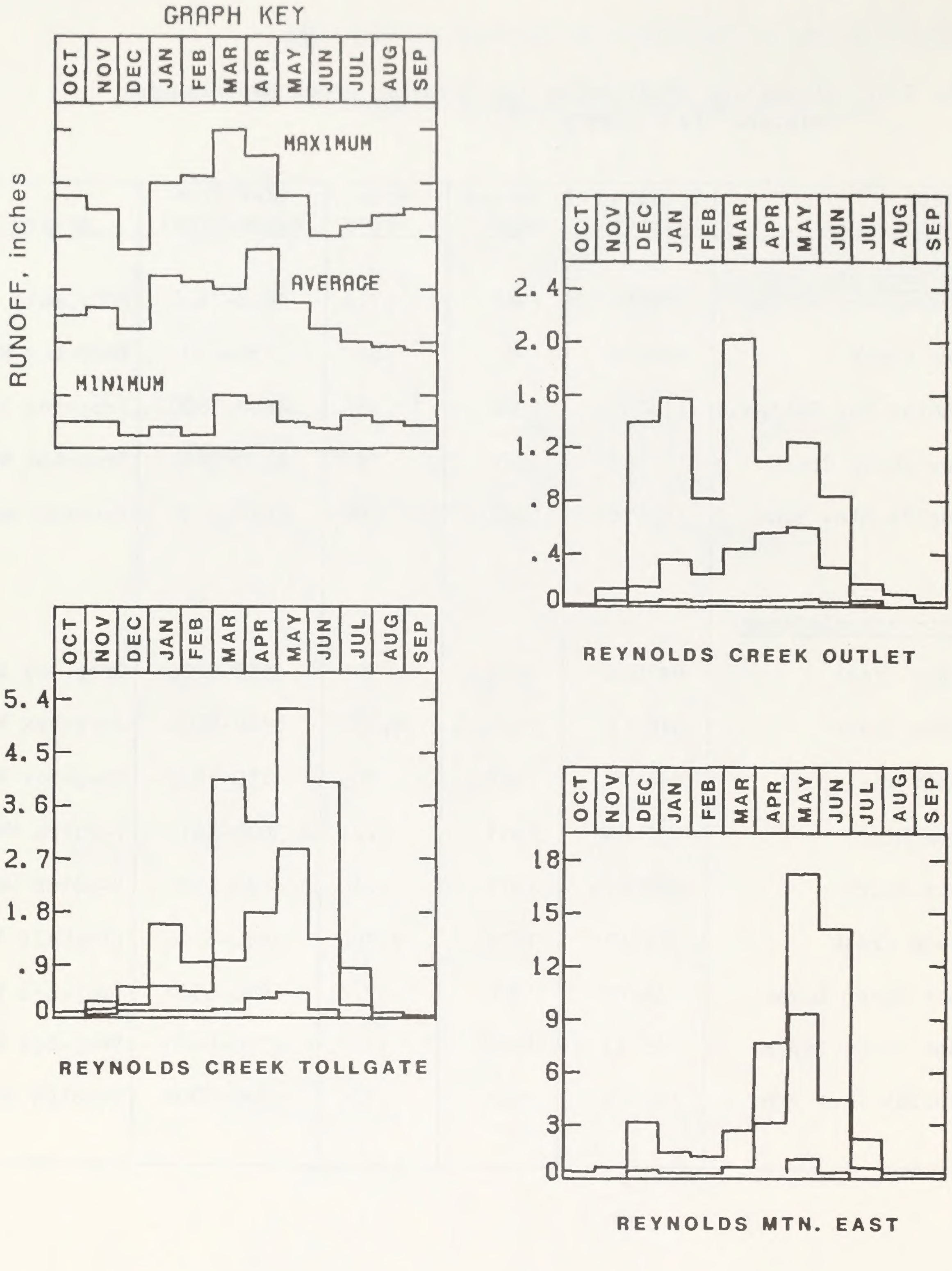


Figure 2.2.--Average, maximum, and minimum monthly runoff - selected Reynolds Creek Watershed stations in inches.

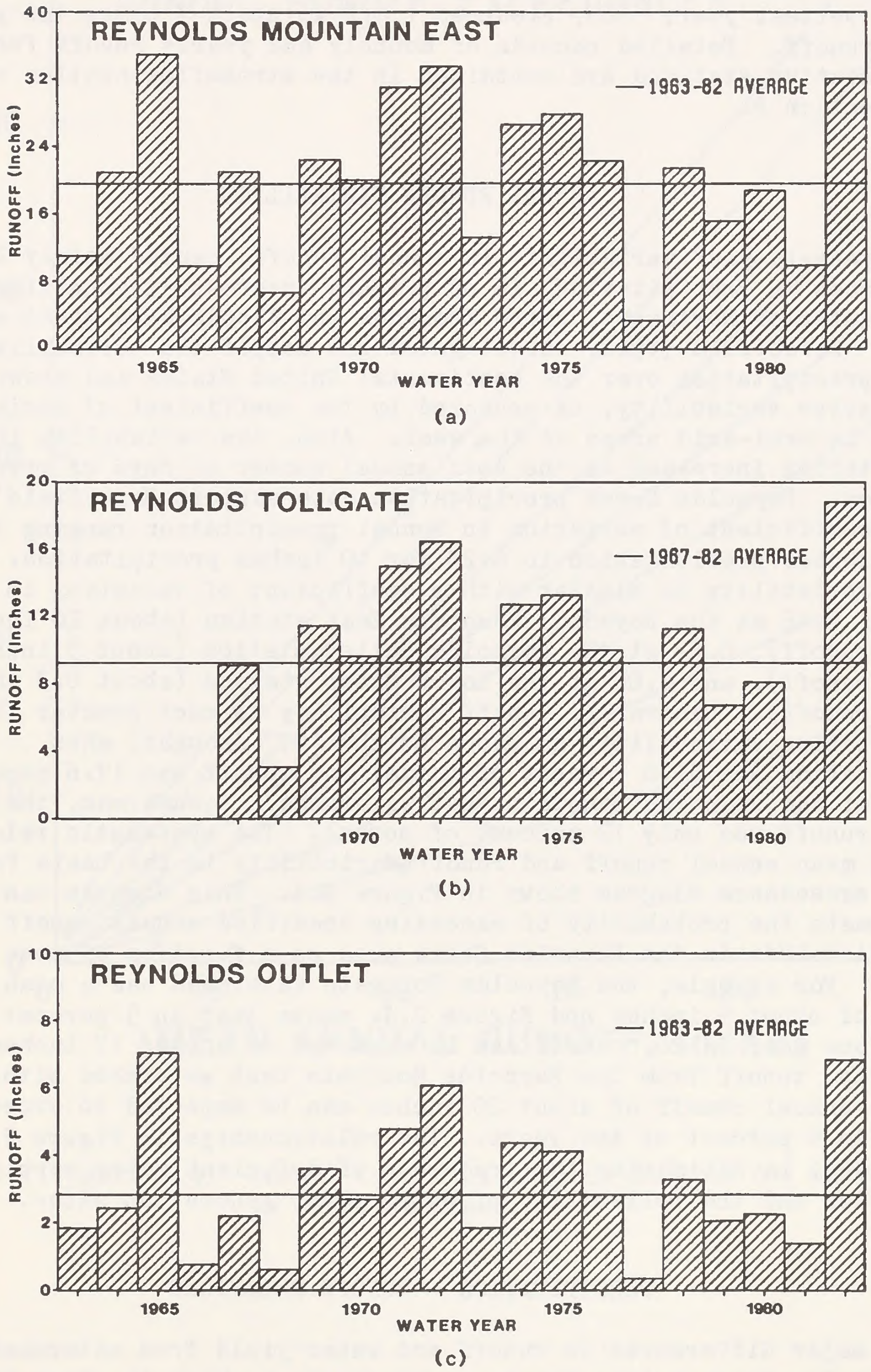


Figure 2.3.--Water year runoff at long-term Reynolds Creek stations: (a) Reynolds Mountain East, (b) Reynolds Tollgate, and (c) Reynolds Outlet.

Reynolds Outlet is influenced by diversions for irrigation. The driest year of record, 1977, produced only 10-18 percent of mean annual runoff and the wettest year, 1965, produced 1 1/2 to about 3 times the mean annual runoff. Detailed records of monthly and yearly runoff from representative stations are contained in the streamflow section of Vol. III., Section B.

ANNUAL RUNOFF VARIABILITY

The year-to-year variability in annual runoff, caused mainly by differences in precipitation, is of primary interest in mountainous areas of the interior Northwest, where droughts and floods have great economic impact. Hershfield (1962) investigated and mapped the variability in annual precipitation over the continental United States and showed that the relative variability, as measured by the coefficient of variation, was greater in semi-arid areas of the west. Also, the variability in annual precipitation increased as the mean annual number of days of precipitation decreased. Reynolds Creek precipitation data support Hershfield's studies with a coefficient of variation in annual precipitation ranging from 0.19 for 40 inches precipitation to 0.24 for 10 inches precipitation. Annual runoff variability is similar with a coefficient of variation in annual flows of 0.46 at the Reynolds Mountain East station (about 20 inches mean annual runoff), 0.62 at the Reynolds Outlet station (about 3 inches mean annual runoff), and 1.06 at the Lower Sheep station (about 0.3 inch mean annual runoff). Generally, runoff variability is much greater than precipitation variability, as shown by the 1977 drought, when precipitation was 51.6 percent of normal and runoff was 17.6 percent of normal at the Reynolds Mountain East watershed. Downstream, the Reynolds Outlet runoff was only 12 percent of normal. The systematic relationship between mean annual runoff and runoff variability is the basis for the runoff exceedance diagram shown in Figure 2.4. This diagram can be used to estimate the probability of exceeding specified annual runoff amounts from watersheds in the Reynolds Creek area as a function of mean annual runoff. For example, the Reynolds Tollgate watershed has a mean annual runoff of about 9 inches and Figure 2.4. shows that in 5 percent of the years, one year in 20, runoff can be expected to exceed 17 inches. Similarly, runoff from the Reynolds Mountain East watershed with an average annual runoff of about 20 inches can be expected to exceed 36 inches in 5 percent of the years. The relationships in Figure 2.4. are also useful in estimating the frequency of deficient water supply for irrigation and the reliability of water power generation sites.

PRECIPITATION - RUNOFF RELATIONS

The major differences in runoff and water yield from watersheds within Reynolds Creek are mainly due to precipitation, which is strongly influenced by elevation and topography. The relationship between mean annual precipitation and mean annual runoff for 11 watersheds in Reynolds Creek is

$$Q = -10.37 + 0.73P \quad (r^2 = 0.96) \quad \text{or} \quad Q = 0.73\,(P-14.2) \qquad [2.1]$$

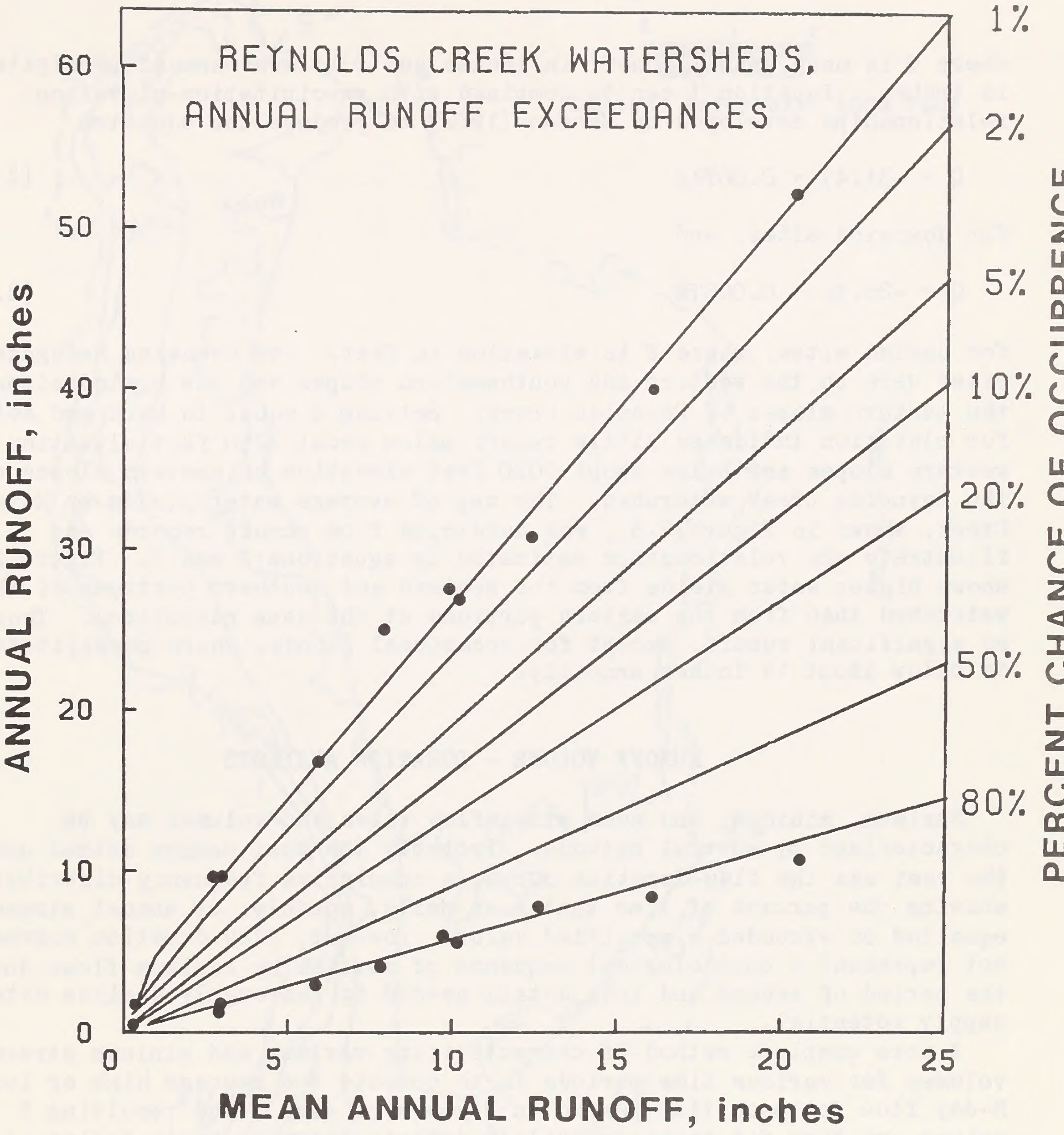


Figure 2.4.--Annual runoff exceedance diagram for watersheds in Reynolds Creek.

where Q is mean annual runoff in inches and P is mean annual precipitation in inches. Equation 1 can be combined with precipitation-elevation relationships developed by Hanson (1982) to produce the equation

$$Q = -31.47 + 0.0074E \qquad [2.2]$$

for downwind sites, and

$$Q = -28.46 + 0.0057E \qquad [2.3]$$

for upwind sites, where E is elevation in feet. The downwind raingage sites were on the western and southwestern slopes and the upwind sites on the eastern slopes of Reynolds Creek. Setting Q equal to zero and solving for elevation indicates little runoff below about 4250 feet elevation on western slopes and below about 5020 feet elevation on eastern slopes of the Reynolds Creek watershed. The map of average water yields on Reynolds Creek, shown in Figure 2.5., was developed from runoff records and illustrate the relationships estimated by equations 2 and 3. Figure 2.5. shows higher water yields from the western and southern portions of the watershed than from the eastern portions at the same elevations. There is no significant runoff, except for occasional floods, where precipitation is below about 14 inches annually.

RUNOFF VOLUME - DURATION ANALYSIS

Maximum, minimum, and mean streamflow rates and volumes may be characterized by several methods. Probably the most common method used in the past was the flow-duration curve, a cumulative frequency distribution showing the percent of time that mean daily, monthly, or annual streamflow equalled or exceeded a specified value. However, flow duration curves do not represent a chronological sequence of maximum or minimum flows during the period of record and lack detail needed to thoroughly analyze water supply potential.

A more complete method of characterizing maximum and minimum streamflow volumes for various time periods is to compute the average high or low M-day flow for each time period in N-years of data. The resulting N values are then fit to a probability distribution to obtain tables of maximum and minimum flow volumes for various time periods. Table 2.2. shows maximum mean runoff volumes for periods ranging from 1 day to 1 year at Reynolds Outlet, Macks Creek, Reynolds Tollgate, and Reynolds Mountain streamflow measuring stations. The mean maximum 1-day runoff volume for 16-19 years of record ranged from 0.125 inch at Reynolds Outlet to 0.635 inch at Reynolds Mountain. Tables showing detailed results of year-by-year and mean-of-record streamflow analysis for the four stations are in Vol. III., Section B to this report. Also, Vol. III., Section B tables show number of consecutive days and total number of days streamflow volumes were above or below 10 well distributed streamflow runoff levels appropriate for each station. These tables are useful in estimating water supplies for irrigation, storage, power generation, or other purposes at each long-term station.

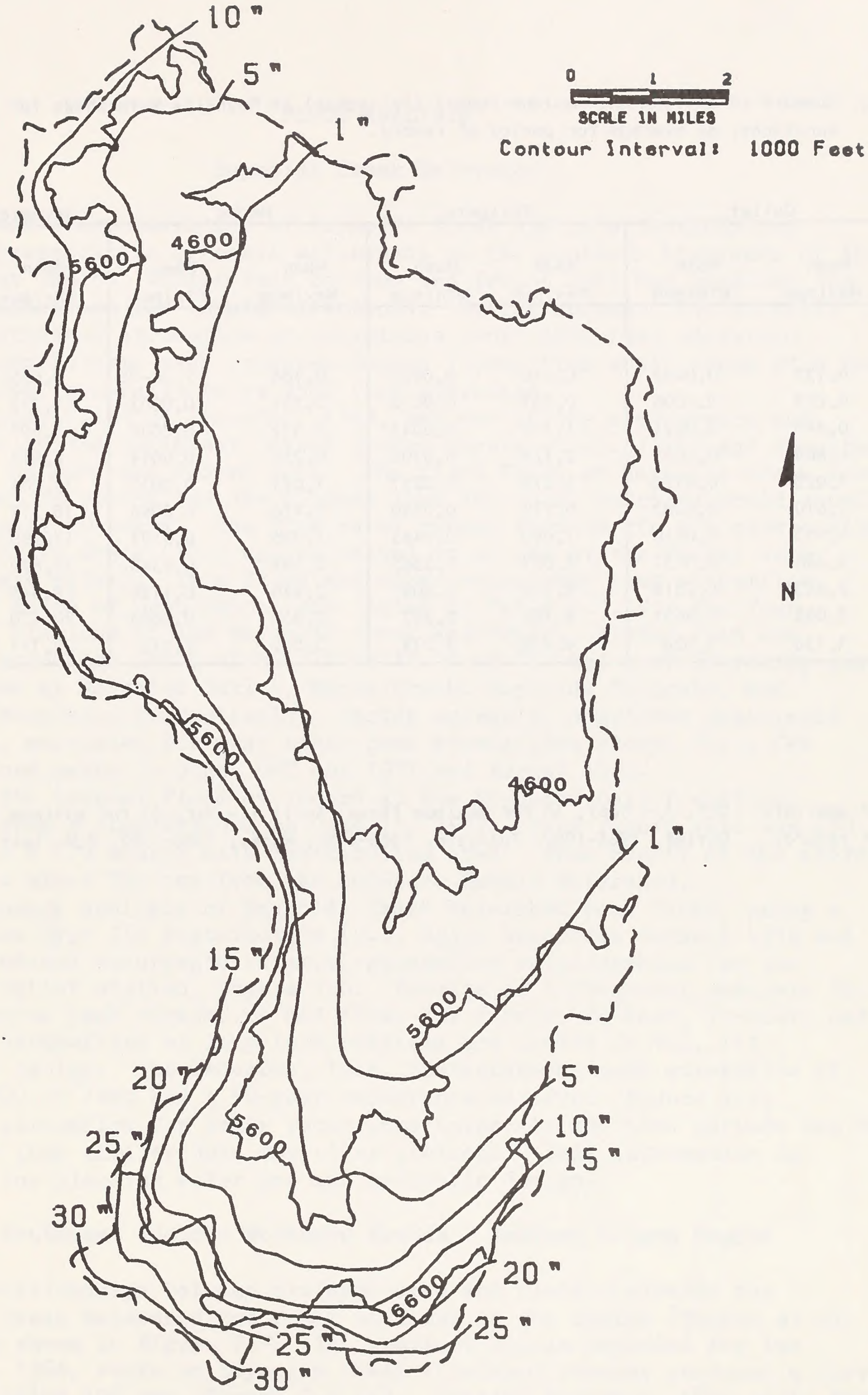


Figure 2.5.--Map of water yield in inches estimated from streamflow records - Reynolds Creek Experimental Watershed.

Table 2.2. Summary of minimum and maximum runoff (in inches) at Reynolds Watersheds for 11 durations, as average for period of record.*

	Outlet		Tollgate		Macks		Reynolds Mtn. East	
	Mean Maximum	Mean Minimum	Mean Maximum	Mean Minimum	Mean Maximum	Mean Minimum	Mean Maximum	Mean Minimum
1 day	0.125	0.0002	0.216	0.0005	0.166	7.0E-05	0.635	0.0010
3 day	0.269	0.0008	0.537	0.0016	0.331	0.0002	1.713	0.0034
7 day	0.445	0.0021	1.138	0.0043	0.512	0.0006	3.693	0.0087
15 day	0.669	0.0051	2.123	0.0106	0.731	0.0014	6.918	0.0215
30 day	1.025	0.0122	3.678	0.0257	1.021	0.0035	11.204	0.0532
60 day	1.610	0.0283	5.779	0.0740	1.476	0.0098	16.211	0.1462
90 day	1.993	0.0518	7.090	0.1443	1.936	0.0191	17.980	0.2679
120 day	2.346	0.0837	8.005	0.2365	2.184	0.0345	18.628	0.4329
183 day	2.883	0.2318	9.142	0.6097	2.440	0.1126	19.646	0.9983
274 day	3.083	0.9651	9.702	2.302	2.539	0.5688	20.430	2.748
1 year	3.130	3.020	9.856	9.274	2.552	2.512	20.711	19.694

* Period of analysis: Oct. 1 - Sept. 30 for maximum flows; April 1 - Mar. 31 for minimum flows.
Period of record: Outlet, 1963-1982; Tollgate, 1966-1982; Macks, 1966-1982; R.M. East 1964-1982.

FLOOD ANALYSIS

Reynolds Creek Watershed

The flood characteristics of Reynolds Creek and subwatersheds are fairly representative of small watersheds in the southern highlands of the Snake River Basin. Winter rain on snow and frozen soil has produced the greatest floods on low to mid elevations. Spring snowmelt has normally produced greatest streamflow at elevations above 6000 feet elevation. Summer thunderstorms have produced severe floods from small areas of a few square miles, generally below 4500 feet elevation.

The winter flood of December, 1964, was one of the most severe and widespread in the northwest United States (Rantz et al. 1965) and resulted from rain on snow and frozen soil. The flood flows at Reynolds Creek were the highest of record and the highest that the local ranchers could recall over the past 70 years. The flow rates ranged from 98 cfs per square mile (csm) at Macks Creek (12.3 square miles) to 43 csm at the Outlet weir (90.2 square miles). This flood and other water year peak streamflow rates and dates of occurrences are listed in Table 2.3. for the four long-term stations on the Reynolds Creek Watershed. Winter rain and snowmelt accounted for 9 of 20, 10 of 17, 6 of 17, and 1 of 20 yearly peak streamflows at Reynolds Outlet, Macks Creek, Reynolds Tollgate, and Reynolds Mountain, respectively. Spring snowmelt, sometimes associated with rain, accounted for most other peak streamflows except for a few thunderstorm peaks in June 1967 and 1977 and August 1968.

The fifth largest flood of record at the Reynolds Outlet station resulted from a thunderstorm on June 11, 1977. Peak runoff rate was 250 csm from a 4 1/2 square mile contributing area. Peak runoff at the storm center was about 750 csm from the 205-acre Summit watershed.

A frequency analysis of Reynolds Creek Watershed peak flows, using a log-Pearson Type III distribution (U.S. Water Resources Council 1976 and 1977), produced recurrence interval-streamflow relationships for the Reynolds Outlet station, Figure 2.6. Results of a frequency analysis for instantaneous peak streamflow and flows for 6-hour, 24-hour, 72-hour, and 192-hour streamflows at long-term stations are listed in Vol. III., Section B tables. The December, 1964, instantaneous peak streamflow of nearly 4000 ft^3/sec had a 50-year recurrence interval, Figure 2.6. Expected streamflow for other recurrence intervals and time periods can be estimated from similar data for other stations. This information is valuable for planning water use and hydraulic design.

Southwest Idaho - Northern Nevada - Eastern Oregon Region

The relationships between drainage area and flood discharge for Reynolds Creek Watershed and other stations in the region (Thomas et al. 1973) are shown in Figure 2.7. The greatest floods recorded for the December, 1964, storm on Reynolds Creek Watershed streams produced a curve slightly below 100 csm, Figure 2.7.(a). Similar December, 1964, data from other streams in the region produced the relationship shown in Figure 2.7.(b), which shows a curve with higher intercept and lesser slope than for Reynolds Creek stations. The thunderstorm flood relationship (excluding Boise Front streams), Figure 2.7.(c), also centers about the 100 csm line but data were limited to watersheds less than 100 square miles. The curve, Figure 2.7.(d), for the 1959 thunderstorm floods on the

Table 2.3. Water year peak streamflow rates (ft^3/sec) and dates of occurrences, long-term Reynolds Creek stations.

STATION

WATER YEAR	REYNOLDS OUTLET			MACKS CREEK			REYNOLDS TOLLGATE			REYNOLDS MTN. EAST		
	Date	Time	Flow	Date	Time	Flow	Date	Time	Flow	Date	Time	Flow
1963	1-31	1700	2331	--	--	--	--	--	--	4-29	1500	4.16
1964	1-25	2200	188	--	--	--	--	--	--	5-16	1600	3.60
1965	12-23	30	3850	--	--	--	--	--	--	12-23	215	10.70
1966	4- 1	2245	59	3-13	1800	12	4- 1	1945	59	5- 5	1900	1.43
1967	6- 7	1630	265	1-21	1806	90	6- 7	1358	288	5-22	1604	5.44
1968	2-21	1500	327	2-21	1426	44	2-21	1252	186	8-10	2100	1.48
1969	1-21	200	900	1-21	26	307	1-21	442	405	5-12	1650	3.88
1970	1-27	415	729	1-27	356	24	1-27	414	240	5-17	1700	5.89
1971	1-18	515	540	1-18	430	281	1-18	638	196	5- 4	1605	5.77
1972	3- 2	1800	678	3- 2	400	143	3- 2	1742	271	6- 6	1500	6.26
1973	4-17	816	166	4-16	2328	54	4-17	38	146	5- 8	1600	3.31
1974	3-29	2236	291	3-14	1626	71	3-29	2118	195	5- 7	1610	4.33
1975	3-25	946	281	2-28	436	142	6- 2	1554	231	6- 2	1400	9.27
1976	4- 5	1932	140	12- 6	1514	35	5-10	1906	130	5-13	1650	4.59
1977	6-11	1724	1119	6-11	1138	19	4- 8	1842	17	4-16	1755	0.93
1978	4-26	645	589	4-26	718	86	4-26	357	230	5-14	1545	4.50
1979	1-11	1416	1663	1-11	1248	300	1-11	1203	121	5-15	1535	3.52
1980	5- 6	1545	259	1-12	1634	37	4-23	2000	163	4-22	1530	3.69
1981	4-20	833	251	2-14	709	47	2-16	1935	169	4-20	245	4.54
1982	2-15	145	2082	2-15	44	263	12-19	2140	427	5-22	1700	3.54
Mean			836			170			204			4.54
S.D.			964			201			106			2.35

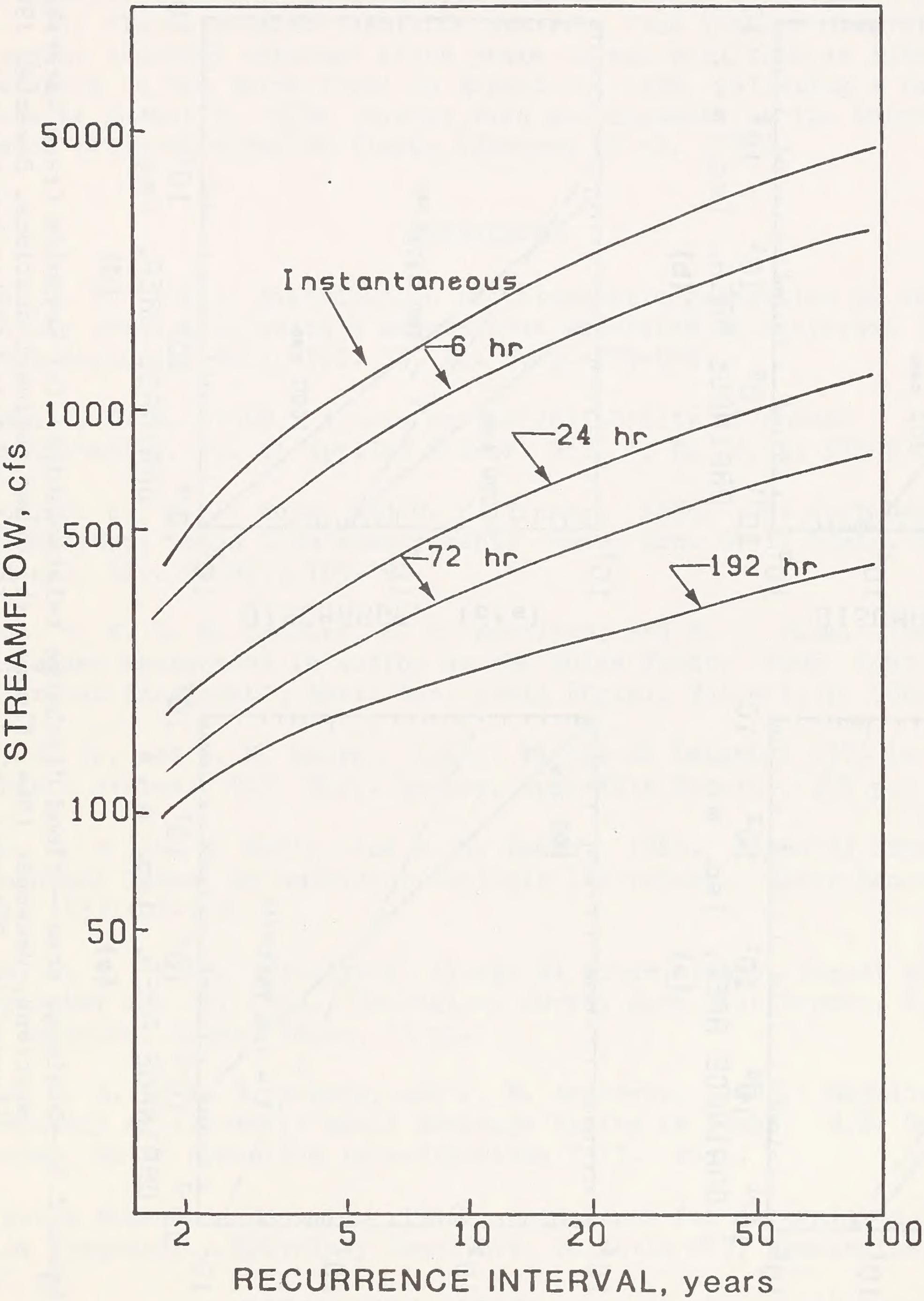


Figure 2.6.--Recurrence interval - streamflow relationships for Reynolds Creek Outlet stations.

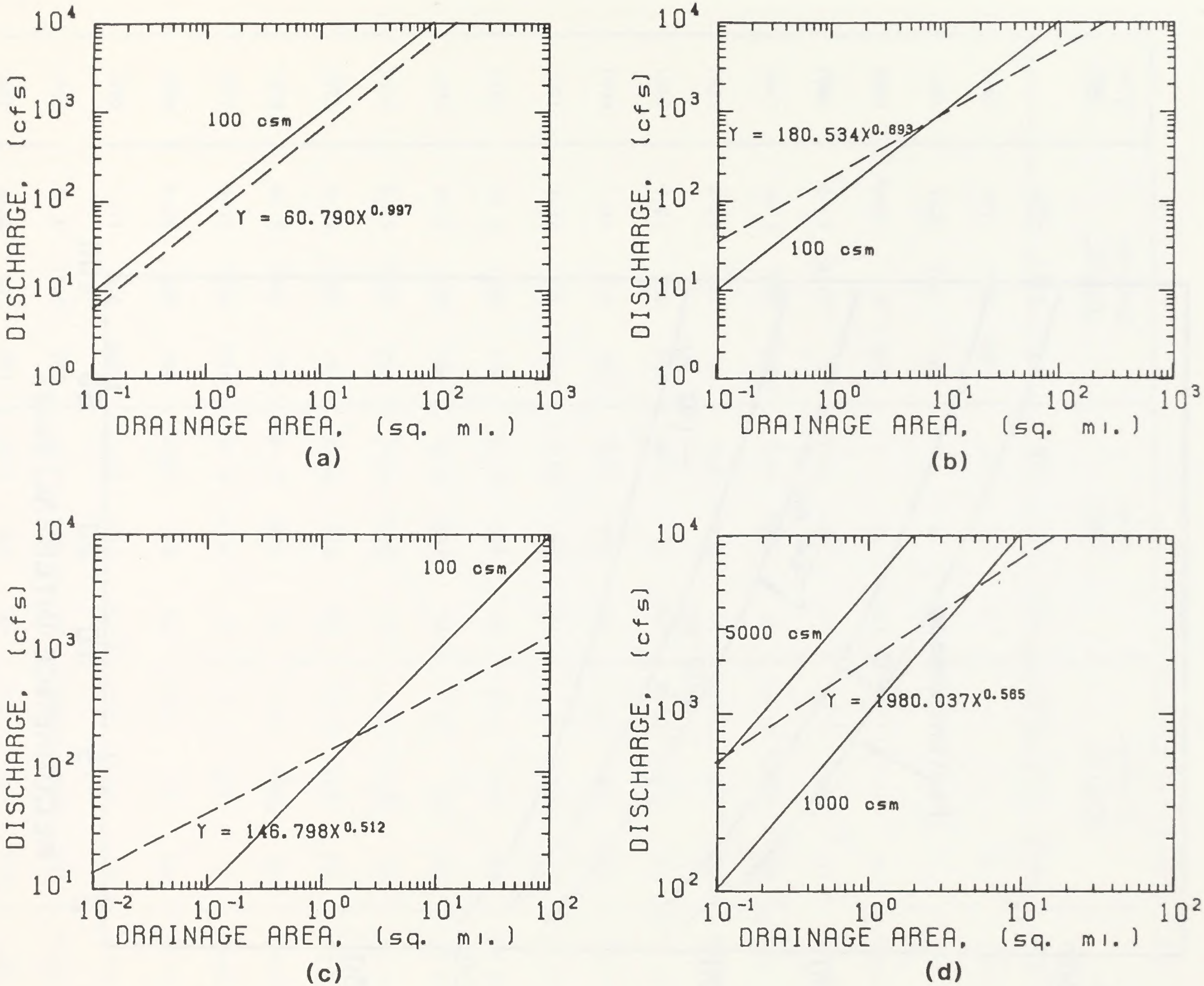


Figure 2.7.--Drainage area - flood discharge relationships: (a) Reynolds Creek Watershed stations, December 1964, floods; (b) Other regional stations, December 1964, floods; (c) Regional thunderstorm floods (excluding Boise Front); and (d) Boise Front thunderstorm floods, August 1959, following a range fire.

Boise Front following a fire on the watersheds (Thomas 1963) shows extremely high discharges from small watersheds. All the floods greater than 100 csm were from drainage areas less than 40 square miles and all floods greater than 200 csm were from drainage areas less than 5 square miles. All floods greater than 1000 csm were from intense thunderstorms. The largest recorded regional flood peaks in csm were from an intense thunderstorm on the Boise Front on August 20, 1959, following a range fire on the area August 3, 1959. Winter rain and snowmelt on the Boise Front have also produced damaging floods (Johnson et al. 1980).

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Chapter 3

EROSION AND SEDIMENT

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Chapter 3

EROSION AND SEDIMENT

CONTENTS

Streambank Erosion

Thunderstorm Erosion - July 1978

INTRODUCTION

Erosion and sediment studies were initiated on the Reynolds Creek Experimental Watershed in connection with runoff measurements. Because of visible erosion and stream sediment transport, a network of watershed sediment sampling stations was established, Figure 2.1. Stations are described in Table 3.1. The major objectives of the erosion and sediment program were to accurately sample sediment transport at key stations and to determine sediment yields from instrumented watersheds, especially during storm runoff.

SEDIMENT SAMPLING

Hand-held U.S. DH-48 depth-integrating sediment samplers were used to determine suspended sediment concentrations at runoff measuring stations, stream wading sites, and at sampling sites from bridges. Depth-integrated sediment sample data were used to calibrate pumping samplers. Sediment sampling and analysis procedures described by Allen (1981) apply to studies on Reynolds Creek.

Automatic suspended sediment pumping samplers (U.S. PS-67, U.S. PS-69, Chickasha, and ISCO) were used at watershed and streamflow measuring stations beginning in 1969. U.S. PS-67 and U.S. PS-69 suspended sediment samplers were used at large weirs, drainage areas exceeding 6 mi^2, where coarse sediment was often in suspension, and Chickasha and ISCO samplers were used at smaller watershed stations with coarse bedload catchment tanks. All pumping samplers were equipped with timers for adjusting sampling intervals. Pumping sampler intakes were located in drop-box weirs (Johnson et al. 1966), where such devices were available to provide favorable conditions for mixing and representative sampling.

Coarse bedload material from small watersheds was collected and measured periodically in catchment tanks to supplement suspended sediment data. Helley-Smith bedload samplers (Helley and Smith 1971; Emmett 1980), were used to determine bedload transport rates and particle sizes during some high runoff events on major streams to supplement suspended sediment transport data. Bedload samplers with six-inch orifices were operated from a backhoe on bridges and samplers with three-inch orifices were hand-held while wading or sampling from bridges. The particle size of bedload transported during high flows was often too large for sampling with available equipment. Special sampler bags were developed for sampling bedload with excessive organic material (Johnson et al. 1977). Bedload transport was generally not sampled during the greatest floods because these events were unpredictable or personnel and equipment were not available at that time.

Table 3.1.--Descriptions of sediment sampling station and contribution areas, Reynolds Creek Watershed, see Figure 2.1.

Sediment Sampling Station	Period of Record	Type Suspended Sampler	Bedload Sampling Method	Drainage Area, Acres
Reynolds Mtn. East	1969-82	Chickasha	Tank	100
Reynolds Cr. Tollgate	1967-82	PS-67, 69	Helley-Smith	13,453
Macks Creek	1968-82	PS-67	Helley-Smith	7,846
Reynolds Creek Outlet	1967-82	PS-67, 69	Helley-Smith	57,754
Temporary Stations:				
Reynolds Mtn. West	1975-82	None	Tank	126
Upper Sheep	1970-74	Chickasha	Tank	64
Lower Sheep	1975-82	None	Tank	33
Nancy	1972-82	ISCO	Tank	3.1
Whiskey Hill	1965-75	None	Pond	120
Flats	1972-82	DH-48	Tank	2.2
Summit	1967-75	Chickasha	Pond	205
Salmon Creek	1968-74	DH-48	None	8,990

SEDIMENT SAMPLE ANALYSIS AND DATA PROCESSING

Suspended sediment samples were analyzed by standard laboratory procedures using filter or evaporation methods to determine sediment concentrations. Next, the data were plotted with associated streamflow records, Figure 3.1., and digitized to compute sediment transport rates and sediment yields for selected time intervals, see printout copy, Table 3.2. When automatic pumping samplers failed to operate, sediment concentrations were estimated using appropriate runoff-sediment rating curves from similar events. During periods of low streamflow, average daily sediment concentrations were estimated from intermittent sampling.

Bedload samples were dried, weighed, and analyzed by sieving to determine particle sizes for a wide range of streamflow and sampling locations across the stream channels. Bedload transport rates were computed for sites where data were collected to determine total sediment yields, Table 3.2.

WATERSHED SEDIMENT TRANSPORT AND YIELDS

Suspended Sediment Concentrations

Yearly maximum suspended sediment concentrations, concurrent peak streamflow rates, and dates of occurrence are shown in Tables 3.3a. and 3.3b., for long-term sediment sampling stations, Figure 2.1. Sediment samples were generally not obtained exactly at peak sediment concentrations; but, the maximum concentrations were estimated from curves connecting sample data points on sediment graphs. Highest sediment concentrations were caused by thunderstorms, such as shown for the Reynolds Outlet station in 1977 and the Reynolds Tollgate station in 1967. Snowmelt sediment concentrations were generally less for comparable flow rates.

Bedload Transport Studies

Helley-Smith bedload samplers (Helley and Smith 1971), were used on Reynolds Creek Watershed streams to determine bedload transport rates (Johnson and Smith 1978; Johnson et al. 1977). Although sampling was limited to short periods and a few stations, results showed the importance of large sampler bags and numerous samples in accurately determining sediment transport rates and particle sizes for a wide range of streamflow conditions. Much additional research is needed if bedload transport is to be fully understood and accurately predicted.

Sediment Yields

The sediment yields from long-term sampling stations on the Reynolds Creek Watershed, Figure 2.1, by streamflow sampling are summarized in Table 3.4. Bedload sampling data for the Macks Creek and Reynolds Outlet stations were inadequate for accurate determination of total load but limited sampling indicates that bedload is about 10-20 percent of total load at these watershed stations. Sediment yields ranged widely from year to year and were nearly zero at most stations in 1977, a severe drought year. Unfortunately, sampling stations were not in operation during the

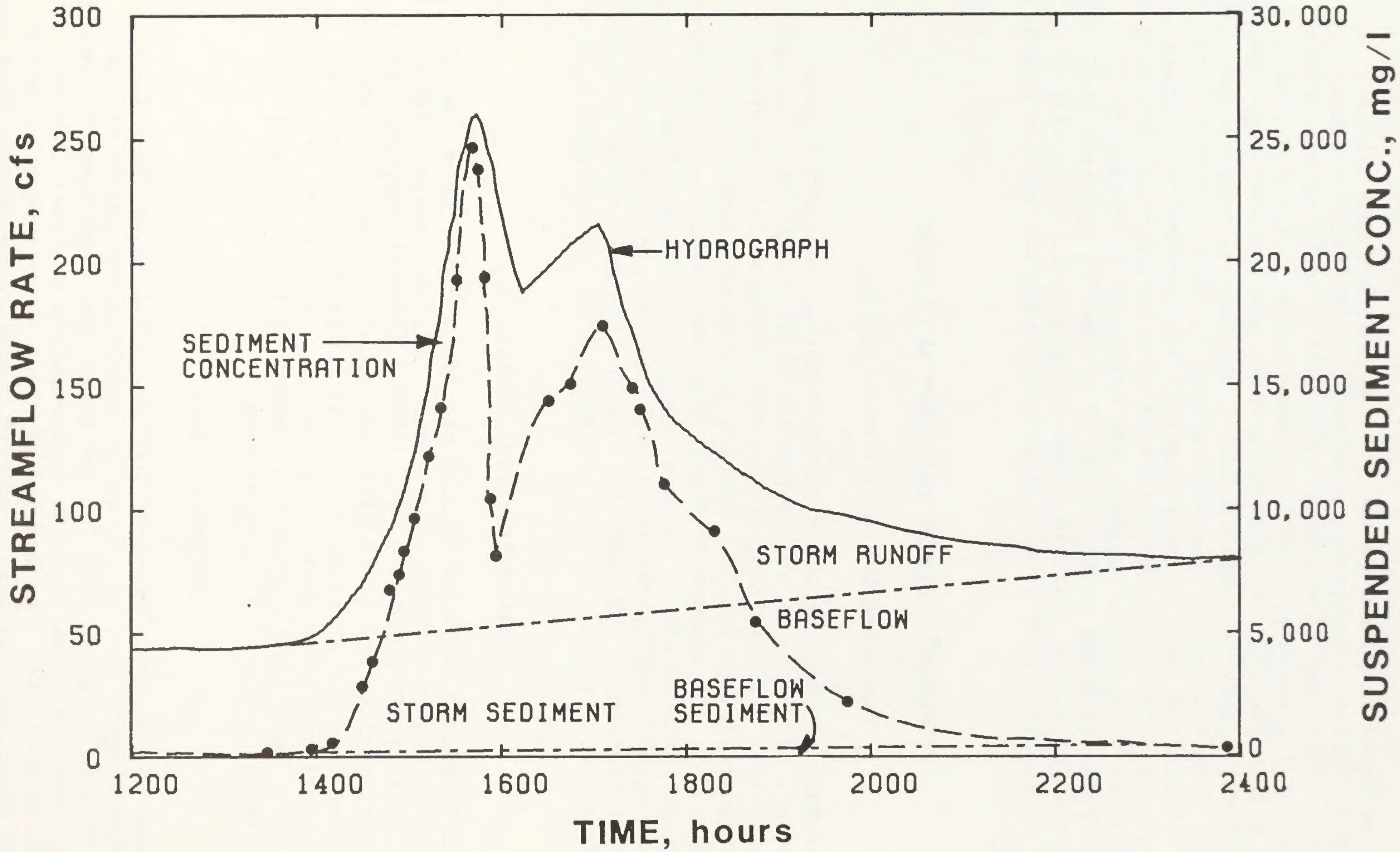

Figure 3.1.--Streamflow-sediment concentration graph, Reynolds Creek Watershed.

Table 3.2.--Example of computer printout of sediment data.

REYNOLDS CREEK EXPERIMENTAL WATERSHEO BOISE, IDAHO

LOCATION 68116083 | YEAR 1980 | TOLLGATE WEIR 13,453 ACRES

JULIAN DAY	MO	DA	YR	MILITARY TIME	DISCHARGE CFS	ACCUMULATED RUNOFF (IN)	CONC.	ACCUM. SUSP. TONS	BEDLOAD RATE KG/MIN	ACCUM. BED. TONS	TOTAL SED. TONS
113	4	22	80	301	77.7523	2.44156	265.	5.978753E+02	6.751	3.000470E+01	6.278802E+02
113	4	22	80	1131	66.1104	2.48663	75.	6.095499E+02	3.492	3.023567E+01	6.397858E+02
113	4	22	80	1256	69.8517	2.49373	175.	6.109021E+02	4.367	3.052456E+01	6.414268E+02
113	4	22	80	1359	81.0723	2.49957	550.	6.141282E+02	8.001	3.105383E+01	6.451823E+02
113	4	22	80	1610	98.1365	2.51399	1575.	6.374755E+02	17.391	3.220428E+01	6.696799E+02
113	4	22	80	1615	100.0608	2.51460	1640.	6.389665E+02	18.820	3.344920E+01	6.724159E+02
113	4	22	80	1720	102.9939	2.52271	1505.	6.583929E+02	21.165	3.484924E+01	6.932424E+02
113	4	22	80	2015	94.3625	2.54392	550.	6.916089E+02	14.829	3.583018E+01	7.274393E+02
113	4	22	80	2400	81.9168	2.56829	320.	7.077581E+02	8.345	3.638222E+01	7.441404E+02
114	4	23	80	1158	68.3387	2.63456	95.	7.287112E+02	3.995	3.664651E+01	7.653578E+02
114	4	23	80	1322	71.3868	2.64177	120.	7.298922E+02	4.771	3.696208E+01	7.668544E+02
114	4	23	80	1534	79.4007	2.65400	160.	7.325004E+02	7.352	3.744839E+01	7.699489E+02
114	4	23	80	1809	83.6233	2.66952	165.	7.363438E+02	9.075	3.804869E+01	7.743926E+02
114	4	23	80	1856	87.1072	2.67445	250.	7.379022E+02	10.712	3.875732E+01	7.766597E+02
114	4	23	80	1914	92.5123	2.67643	440.	7.389463E+02	13.682	3.966240E+01	7.786088E+02
114	4	23	80	1926	118.5223	2.67799	795.	7.404100E+02	37.454	4.213998E+01	7.825501E+02
114	4	23	80	1944	151.5405	2.68098	1950.	7.466548E+02	101.693	4.886700E+01	7.955220E+02
114	4	23	80	1951	154.1089	2.68229	2215.	7.508253E+02	108.883	5.606959E+01	8.068951E+02
114	4	23	80	2000	163.3268	2.68405	2870.	7.576241E+02	137.881	6.519040E+01	8.228148E+02
114	4	23	80	2015	163.3268	2.68706	3020.	7.711306E+02	137.881	7.431120E+01	8.454420E+02
114	4	23	80	2045	134.3560	2.69254	2880.	7.957894E+02	62.350	7.843565E+01	8.742252E+02
114	4	23	80	2124	117.4416	2.69857	2575.	8.208596E+02	36.085	8.082267E+01	9.016824E+02
114	4	23	80	2145	116.3674	2.70159	2375.	8.322341E+02	34.762	8.312220E+01	9.153564E+02
114	4	23	80	2255	104.9809	2.71111	1820.	8.626536E+02	22.874	8.463551E+01	9.472890E+02
114	4	23	80	2400	101.0322	2.71933	1275.	8.820497E+02	19.573	8.593008E+01	9.679799E+02
115	4	24	80	213	92.5123	2.73515	655.	9.053004E+02	13.682	8.683517E+01	9.921357E+02
115	4	24	80	829	92.5123	2.77788	350.	9.380215E+02	13.682	8.774025E+01	1.025762E+03
115	4	24	80	1017	106.9933	2.79112	820.	9.498196E+02	24.709	8.937476E+01	1.039195E+03
115	4	24	80	1051	110.0598	2.79565	875.	9.556737E+02	27.716	9.120820E+01	1.046882E+03
115	4	24	80	1246	102.0099	2.81063	600.	9.725087E+02	20.355	9.255466E+01	1.065064E+03
115	4	24	80	1612	97.1838	2.83584	385.	9.914246E+02	16.715	9.366039E+01	1.085085E+03
115	4	24	80	2016	97.1838	2.86498	280.	1.006184E+03	16.715	9.476611E+01	1.100951E+03
115	4	24	80	2400	87.9930	2.89046	200.	1.015502E+03	11.162	9.550449E+01	1.111007E+03
116	4	25	80	1221	73.7314	2.96407	85.	1.031486E+03	5.440	9.586436E+01	1.127351E+03
116	4	25	80	1613	78.5736	2.98578	100.	1.034546E+03	7.045	9.633040E+01	1.130876E+03
116	4	25	80	1858	87.1072	3.00257	195.	1.038320E+03	10.712	9.703903E+01	1.135359E+03
116	4	25	80	2400	80.2336	3.03362	110.	1.045533E+03	7.670	9.754640E+01	1.143080E+03
117	4	26	80	1144	69.8517	3.09852	55.	1.053693E+03	4.367	9.783529E+01	1.151528E+03
117	4	26	80	1330	71.3868	3.10772	50.	1.054428E+03	4.771	9.815086E+01	1.152579E+03
117	4	26	80	1630	86.2273	3.12515	160.	1.057216E+03	10.279	9.883085E+01	1.156047E+03
117	4	26	80	1756	87.9930	3.13435	220.	1.059881E+03	11.162	9.956923E+01	1.159450E+03
117	4	26	80	2002	87.9930	3.14797	175.	1.063980E+03	11.162	1.003076E+02	1.164288E+03
117	4	26	80	2400	80.2336	3.17257	125.	1.069601E+03	7.670	1.008150E+02	1.170417E+03

Table 3.3a.--Dates of occurrence, maximum suspended sediment concentration, and concurrent peak flow rate by water year at long-term sediment sampling stations.

Water Year	Station: Reynolds Creek at Outlet			Station: Macks Creek		
	Date	Maximum conc., mg/l	Peak flow, ft /sec	Date	Maximum conc., mg/l	Peak flow, ft /sec
1967	6-7	24,700	265	1-21	---	90
1968	2-21	16,950	327	2-21	17,850	44
1969	1-21	29,170	900	1-20	20,280	327
1970	1-27	15,000	729	1-27	20,300	246
1971	1-18	23,000	540	1-18	19,950	273
1972	3-2	14,940	678	6-9	30,000	82
1973	4-17	9,990	166	4-14	16,000	50
1974	3-29	6,400	291	3-14	6,930	71
1975	3-25	4,130	281	2-28	7,400	143
1976	4-5	880	140	1-7	1,110	33
1977	6-11	100,000	1,119	6-11	600	19
1978	4-26	6,365	589	4-26	5,000	86
1979	1-11	6,000	1,662	1-11	5,000	300
1980	5-6	24,550	259	1-12	1,000	37
1981	4-20	5,975	251	2-14	1,990	47
1982	2-15	9,000	2,082	2-15	4,990	263

Table 3.3b.--Dates of occurrence, maximum suspended sediment concentration, and concurrent peak flow rate by water year at long-term sediment sampling stations (continued).

Water Year	Reynolds Cr. at Tollgate			Reynolds Mtn. East		
	Date	Maximum conc., mg/l	Peak flow, ft /sec	Date	Maximum conc., mg/l	Peak flow, ft /sec
1967	6-7	58,810	280	5-22	---	5.4
1968	2-21	8,640	189	8-10	---	1.5
1969	1-21	20,000	402	6-10	1,380	2.5
1970	1-27	5,540	237	5-17	650	5.9
1971	1-18	7,010	199	5-4	650	5.6
1972	3-2	8,580	267	6-6	830	6.3
1973	4-17	4,710	145	4-27	370	2.9
1974	3-29	5,200	198	5-7	400	4.3
1975	6-2	4,960	233	6-2	260	9.3
1976	5-10	1,160	130	5-13	220	4.6
1977	4-8	100	17	4-16	60	0.9
1978	4-26	6,000	230	5-14	580	4.5
1979	1-11	1,500	121	5-15	210	3.5
1980	4-23	3,000	163	4-22	300	3.7
1981	2-16	6,375	169	4-20	565	4.5
1982	12-19	7,500	427	5-22	203	3.5

Table 3.4.--Sediment yield in tons at Reynolds Creek Watershed Stations.

Year	Reynolds Mountain East	Macks[1/] Creek	Reynolds Creek at Tollgate	Reynolds[1/] Creek at Outlet
1967	---	---	11,275	13,503
1968	5.5	393	1965	4334
1969	17.0	6332	12,994	39,336
1970	31.1	3585	7242	15,369
1971	18.1	5833	9771	28,641
1972	18.3	5414	8838	37,396
1973	9.4	1147	1203	2415
1974	10.3	1214	2774	5762
1975	14.2	1949	7867	9860
1976	12.4	646	2546	1430
1977	1.0	7	51	3257
1978	12.1	554	2797	8256
1979	9.2	1634	1808	11,674
1980	12.7	87	1778	4237
1981	10.1	143	1340	1867
1982	11.8	2682	16,229	32,518
MEAN tons/year	12.9	2108	5655	13,741
MEAN tons/acre/year	0.13	0.27	0.42	0.24

1/ Suspended sediment only.

greatest floods of January 1963, December 1964, and January 1965. Sediment yields from selected watersheds were reported by Johnson and Smith (1979); Johnson and Smith (1978); and Johnson and Hanson (1976).

Sediment Sources

Small watershed sediment sampling stations (Reynolds Mountain East, Upper Sheep, Lower Sheep, Whiskey Hill, Nancy, Flats, and Summit), Figure 2.1, generally show lower suspended sediment concentrations than downstream stations during major runoff events. Examples of peak sediment concentrations progressing from source areas to downstream stations are shown in Table 3.5. Similar results from frequent sampling progressing downstream during a major runoff event January 18, 1972, are presented in ARS-BLM Interim Report No. 3, 1973. Sediment yields per unit area are 2-3 times greater from downstream stations than from the Reynolds Mountain station, Table 3.4. The additional downstream sediment is apparently from reworking of channel sediment deposits from previous great floods; however, detailed channel surveys have not been made to verify this general observation.

Suspended Sediment-Runoff Relationships

Suspended sediment yields and associated peak flows and volumes for individual runoff events were determined for long-term stations by separating the hydrographs and sedimentgraphs into total and storm components as shown in Figure 3.1. Storm and total peak streamflow, runoff volume, and associated sediment yield data were next divided into rainfall, snowmelt, and mixed rainfall-snowmelt events.

The equation used to determine suspended sediment-runoff relationships for different type events is:

$$Y = a X^b \qquad [3.1]$$

where Y is suspended sediment yield in tons, X is either peak streamflow in ft^3/sec or runoff volume in inches, a is the intercept, and b is the slope of the regression line. Results of the log-log fit to sediment-peak streamflow data are shown in Table 3.6. Generally, correlation coefficients, r, were only slightly greater for total than storm peak streamflow. Overall, peak streamflow explained over 70 percent of the variance in sediment yields for events. The relationship between storm and total volume and suspended sediment yield by event type are shown in Table 3.7. Storm volumes explain a greater percent of variance in sediment yields than total volume. Overall, runoff volumes explain less variance in sediment yields than peak streamflow. The combined influence of peak streamflow and runoff volumes on sediment yield by event type was analyzed by multiplying peak times volume for each event. Results are summarized in Table 3.8 and storm data show slightly improved correlation coefficients from either peak or volume relationships. Storm volume times peak explained about 75 percent of variance in sediment yield, with the largest watershed, Reynolds Creek at Outlet, having the poorest correlation with snowmelt events.

The sediment yield runoff data summary, Table 3.9, shows that (1) rainfall runoff transports only 3 percent or less of event sediment, (2)

Table 3.5.--Suspended sediment concentrations progressing from small source areas to larger drainage area stations downstream (see station locations, Figure 2.1).

Watershed Station	Storm Date 5/3/70	3/23/71	3/2/72	4/16/73	3/17/74
	maximum storm sediment concentration, mg/l				
Source watershed:					
Reynolds Mtn. East	60	2/	80	60	60
Upper Sheep	720	1,060	3,500	210	1,000
Downstream Watershed:					
Reynolds Tollgate	3,170	2,630	8,600	4,700	2,100
Reynolds Outlet	1/	10,000	14,900	4,100	5,000

1/ No sampling - upstream diversions

2/ No storm runoff

Table 3.6.--Summary of suspended sediment (tons)-runoff peak (Ft^3/sec) relationships for long-term Reynolds Creek Watershed sampling stations by event type.

Event Type	No. of Events	Total Peak Parameters a	b	r	Storm Peak Parameters a	b	r
Station: 036068, Reynolds Creek at Outlet							
Rainfall	11	.03145	1.686	0.950	.20821	1.406	0.926
Snowmelt	91	.01262	1.836	0.633	.11295	1.584	0.658
Mixed	140	.00349	2.207	0.855	.06388	1.835	0.885
Station: 046084, Macks Creek							
Rainfall	13	.08533	1.742	0.898	.13716	1.685	0.888
Snowmelt	58	.00717	2.429	0.944	.08067	1.874	0.885
Mixed	89	.02236	2.146	0.919	.12311	1.850	0.912
Station: 116083, Reynolds Creek at Tollgate							
Rainfall	5	.31124	1.117	0.884	.62640	0.931	0.828
Snowmelt	190	.00623	2.046	0.823	.03481	2.101	0.815
Mixed	135	.00781	2.055	0.872	.05273	1.905	0.889
Station: 166076, Reynolds Mountain East							
Rainfall	2	---	---	---	---	---	---
Snowmelt	259	.05729	1.412	0.838	.13534	1.387	0.844
Mixed	110	.07122	1.281	0.820	.13420	1.259	0.836

Table 3.7.--Summary of suspended sediment (tons)-runoff volume (inches) relationships for long-term Reynolds Creek Watershed sampling stations by event type.

Event Type	No. of Events	Total Volume Parameters a	b	r	Storm Volume Parameters a	b	r
Station: 036068, Reynolds Creek at Outlet							
Rainfall	11	594	0.351	0.284	14,096	0.921	0.560
Snowmelt	91	10,131	1.481	0.575	84,096	1.559	0.643
Mixed	140	59,508	1.799	0.808	125,885	1.499	0.845
Station: 046084, Macks Creek							
Rainfall	13	2,136	1.215	0.804	10,117	1.416	0.892
Snowmelt	58	5,536	1.886	0.850	11,590	1.645	0.881
Mixed	89	8,076	1.834	0.877	20,646	1.676	0.910
Station: 116083, Reynolds Creek at Tollgate							
Rainfall	5	3,693	2.102	0.962	24,627	1.746	0.998
Snowmelt	190	1,989	1.710	0.761	104,080	2.046	0.801
Mixed	135	2,875	1.773	0.867	12,713	1.573	0.887
Station: 166076, Reynolds Mountain East							
Rainfall	2	---	---	---	---	---	---
Snowmelt	259	0.612	1.351	0.799	3.764	1.421	0.824
Mixed	110	0.685	1.414	0.787	2.521	1.288	0.787

Table 3.8.--Summary of suspended sediment (tons)-runoff volume (inches) x peak (ft /sec) relationships for long-term Reynolds Creek Watershed sampling stations by event type.

Event Type	No. of Events	Total Volume x Peak Parameters a	b	r	Storm Volume x Peak Parameters a	b	r
Station: 036068, Reynolds Creek at Outlet							
Rainfall	11	77.97863	0.632	0.695	209.92909	0.828	0.887
Snowmelt	91	22.02709	0.867	0.619	109.00230	0.831	0.669
Mixed	140	30.48056	1.048	0.853	189.05261	0.864	0.884
Station: 046084, Macks Creek							
Rainfall	13	35.58315	0.820	0.904	69.47578	0.864	0.943
Snowmelt	58	15.36139	1.132	0.922	48.69363	0.909	0.900
Mixed	89	21.51401	1.030	0.915	68.96678	0.905	0.924
Station: 116083, Reynolds Creek at Tollgate							
Rainfall	5	18.10212	0.773	0.939	26.26707	0.670	0.936
Snowmelt	190	6.05069	0.943	0.795	67.27255	1.052	0.814
Mixed	135	6.85012	0.999	0.891	47.12201	0.900	0.907
Station: 166076, Reynolds Mountain East							
Rainfall	2	---	---	---	---	---	---
Snowmelt	259	.19315	0.698	0.823	.72591	0.714	0.841
Mixed	110	.21272	0.695	0.818	.60709	0.667	0.814

Table 3.9.--Suspended sediment and runoff summary for events at long-term sampling stations, Reynolds Creek Watershed.

	Watershed			
	Reynolds Outlet	Macks Creek	Reynolds Tollgate	Reynolds Mtn. East
Record period analyzed	1967-80	1968-80	1967-80	1969-80
Mean yearly event sediment yield, tons	12,314	2,137	3,805	7.94
Mean yearly event sediment yield, ton/ac.	0.213	0.272	0.283	0.079
Rainfall sediment yield, % of total	2	3	1	0
Snowmelt sediment yield, % of total	7	5	35	66
Mixed event sediment yield, % of total	91	92	65	34
Rainfall runoff, % of total	2	5	<1	0
Snowmelt runoff, % of total	28	19	54	70
Mixed event runoff, % of total	70	76	45	30
Mean yearly watershed runoff, inches	2.94	2.62	9.61	21.48
Event runoff, % of total of above	29	34	33	55
Event suspended sediment, % of total	93	96	73	60

snowmelt runoff transports 5-66 percent of event sediment, (3) mixed rainfall and snowmelt runoff transports 34-91 percent of sediment, (4) event runoff accounts for 29-55 percent of total yearly runoff and transports 60-96 percent of the suspended sediment in streams analyzed.

Sediment Characteristics

Sediment particle-size characteristics determined from sediment collection tanks and sediment samplers were summarized in ARS-BLM Interim Report No. 8, 1978. Particle-size distributions of sediment from different storms range widely in response to streamflow rates and volumes at sampling stations. Generally, particle size increases in years of high runoff and decreases in drought years.

Bedload sediment transport rates and particle-size distributions were determined at a few stations and results were reported by Johnson and Smith (1978). Results of this sampling showed streams on Reynolds Creek to be sediment limiting, probably because of generally stable streambanks and frequent bedrock outcrops. Bedload transport-streamflow-particle-size relationships were determined for medium to high runoff rates, but data were not obtained during greatest floods (Johnson et al. 1977).

SOIL LOSS AND SEDIMENT YIELD PREDICTIONS

Pacific Southwest Inter-Agency Committee (PSIAC) Procedure

The PSIAC procedure (Pacific Southwest Inter-Agency Committee 1968), was tested on Reynolds Creek Watersheds (Johnson and Gebhardt 1982). It was concluded that the procedure provided an acceptable method of estimating watershed sediment yields and comparing effects of different site and management conditions. Predicted sediment yields were within about 15 percent of measured watershed sediment yields on Salmon Creek, Macks Creek, and Reynolds Tollgate watersheds. The procedure showed a reasonable response to changes in grazing and brush control; but, actual sediment yield data from study watersheds was very limited. Further evaluation is needed in wide application of the procedure, especially on small source areas with highly variable cover conditions.

Modified Universal Soil Loss Equation (MUSLE)

Results of applying the MUSLE (Williams 1982; and Williams 1975), to long-term streamflow and sediment data from the Reynolds Creek Watershed were reported (Northwest Watershed Research Center 1982). A summary of fitted coefficients and exponents for the MUSLE are shown in Table 3.10, assuming constant values of K, L, S, C, and P factors for the period of record. The equations, fitted by optimization procedures are different from the Williams equation

$$S = 95\ (Q \times qp)^{0.56} \times K \times LS \times C \times P$$

Table 3.10--MUSLE optimization fitted coefficients and exponents, Reynolds Creek Experimental Watersheds.

STATION	TYPE EVENT	RUNOFF FACTOR	KLSCP	r
Reynolds Outlet	Rainfall total	$s = 0.01\ (Qxq_p)^{1.43}$	0.0166	0.79
	Snowmelt total	$s = 0.02\ (Qxq_p)^{1.26}$	0.0166	0.59
	Mixed total	$s = 1.02\ (Qxq_p)^{0.97}$	0.0166	0.85
	Rainfall storm	$s = 2.28\ (Qxq_p)^{1.02}$	0.0166	0.99
	Snowmelt storm	$s = 1.02\ (Qxq_p)^{1.12}$	0.0166	0.67
	Mixed storm	$s = 266\ (Qxq_p)^{0.58}$	0.0166	0.80
Macks Creek	Rainfall total	$s = 234\ (Qxq_p)^{0.42}$	0.0183	0.71
	Snowmelt total	$s = 0.22\ (Qxq_p)^{1.30}$	0.0183	0.98
	Mixed total	$s = 4.05\ (Qxq_p)^{0.94}$	0.0183	0.97
	Rainfall storm	$s = 178\ (Qxq_p)^{0.51}$	0.0183	0.82
	Snowmelt storm	$s = 1.92\ (Qxq_p)^{1.15}$	0.0183	0.96
	Mixed storm	$s = 26.5\ (Qxq_p)^{0.80}$	0.0183	0.97
Reynolds Tollgate	Rainfall total	$s = 39.1\ (Qxq_p)^{0.50}$	0.0171	0.84
	Snowmelt total	$s = 0.05\ (Qxq_p)^{1.20}$	0.0171	0.73
	Mixed total	$s = 0.02\ (Qxq_p)^{1.50}$	0.0171	0.94
	Rainfall storm	$s = 54.1\ (Qxq_p)^{0.48}$	0.0171	0.79
	Snowmelt storm	$s = 7.64\ (Qxq_p)^{0.94}$	0.0171	0.78
	Mixed storm	$s = 0.10\ (Qxq_p)^{1.26}$	0.0171	0.91
Reynolds Mountain	Snowmelt total	$s = 1.67\ (Qxq_p)^{0.88}$	0.0221	0.63
	Mixed total	$s = 3.48\ (Qxq_p)^{0.67}$	0.0221	0.60
	Snowmelt storm	$s = 7.42\ (Qxq_p)^{0.91}$	0.0221	0.80
	Mixed storm	$s = 11.45(Qxq_p)^{0.53}$	0.0221	0.58

where S is sediment yield in tons, Q is runoff volume in acre-feet, qp is peak flow rate in ft^3/sec, and KLSCP are as defined by (Wischmeier and Smith 1978). Both coefficients and exponents range widely between watersheds and between rainfall, snowmelt, and mixed rainfall-snowmelt events.

The MUSLE shows great potential for predicting sediment yields from individual watersheds where both rainfall and snowmelt events are common; however, much more analysis is needed where snowmelt is a major factor.

Flaxman Sediment Yield Equations

Sediment yield equations (Flaxman 1972), developed for the western United States, were tested on 71 agricultural watersheds (Northwest Watershed Research Center 1977). Results showed acceptable performance on rangeland watersheds, similar to those for which equations were developed. However, equations predicted poorly on forested and cultivated watersheds. Since the equations do not include factors to indicate differences in cover or management, usefulness is generally limited to estimating long-term sediment yields from western rangelands.

Soil Surface Factor (SSF)

A comparison between SSF factor ratings and sediment yields from 5 watersheds in Reynolds Creek showed a very poor relationship (Johnson and Webb 1975). Apparently, the SSF values in the slight to moderate erosion classes, as rated on Reynolds Creek watersheds, were not accurate in estimating sediment yields. The SSF procedure needs field validation if it is to be used in estimating erosion rates or in comparing different site conditions for management decisions.

Application of the Universal Soil Loss Equation (USLE)

The USLE was used to determine effects of grazing and sagebrush eradication on potential erosion at Reynolds Creek watershed sites (Johnson et al. 1980; and Northwest Watershed Research Center 1981). Procedures of Wischmeier and Smith (1978), and Wischmeier (1975), utilize available cover transect data and show effects of climatic and range management differences on potential erosion. Also, additional recommendations by Dissmeyer and Foster (1980), on predicting sheet and rill erosion on forest lands are very helpful in understanding the cause and effect relationships between management practices and erosion using the USLE.

Some conclusions from applying the USLE to Reynolds Creek Watershed sites are:

1. Potential soil loss was significantly less at the end of the grazing season than at peak standing crop;

2. Potential soil loss was significantly greater from 4 grazed plots than from ungrazed plots and not significantly different on 5 grazed and ungrazed plots;

3. Potential soil loss was not significantly different on areas sprayed to control sagebrush than from ungrazed control areas;

4. Cutting and removing sagebrush caused a highly significant increase in potential soil loss compared with control areas; and

5. Sediment yields from a few watershed stations were only about 25 percent of computed on-site soil losses.

Rainfall Simulator Soil Loss Studies

A rotating-boom rainfall simulator (Swanson 1965), on loan from the Southwest Rangeland Watershed Research Center was used to measure soil loss from 30 plots 10 feet wide and 35 feet long in 1982. Plots were tilled, clipped, grazed, and ungrazed to determine USLE soil erodability and cover factors for sagebrush rangeland conditions. Results of the study were summarized by Johnson et al. (1983).

USLE soil erodibility factor, K, values determined by the soil erodibility nomograph (Wischmeier and Smith 1978), and from the rainfall simulation study on three Reynolds Creek sites are compared in Table 3.11 (Johnson et al. 1983). The erodibility values by the nomograph, K_N, using soil samples from the plots, ranged from 6-46 percent greater than values from the rainfall simulation data. The K_L values, computed from data on plots rototilled within 2 months of applying simulated rainfall, were determined after adjustment for non-fallow conditions. Overall, K_N values appear acceptable for estimating soil loss from tilled plots on the study sites.

USLE cover-management factor, C, values were determined for the plots by rainfall simulation, C_L, and by the subfactor procedure, C_S, of Dissmeyer and Foster (1981). Results are summarized in Table 3.12. Comparisons of estimated C_S with simulation C_L values show fair agreement on grazed plots, higher C_S values on ungrazed plots, and a mix of higher and lower values on clipped plots. The poor overall relationship between C_L and C_S values shows the difficulty of accurately estimating cover-management factor values on rangeland sites with variable vegetation, litter, and rock cover, rooting characteristics, and depression storage. This study illustrates the need for additional research in applying the USLE on sagebrush rangeland.

Sediment Yield Data Summaries

Yearly sediment yields from long-term stations, Table 3.4, were summarized from numerous suspended sediment samples and from limited bedload samples, see example Table 3.2. Extensive detailed sediment files and daily and monthly data summaries are in computer-accessible storage and selected stations are included in Vol. III., Section C to this report.

Sediment yields range widely from year to year, with near zero amounts in extreme drought years and about one ton/acre/year at downstream stations in years of high runoff. Daily sediment yields for a given streamflow rate can also be highly variable depending on frozen soil, rain-on-snow, soil water conditions, and rainfall distributions. Although

Table 3.11.--Comparisons between soil erodibilities[1/] by the nomograph, K_N, and from linear regression of rainfall simulator data, K_L.

STUDY SITE AND PLOT	SOIL ERODIBILITY, K_N: SCS SOIL PITS	SOIL ERODIBILITY, K_N: PLOT SOIL SAMPLES	SOIL ERODIBILITY, K_L: RAINFALL SIMULATION
REYNOLDS CREEK:			
FLATS - FTR3	.372	.432	.326
FTR9	----	.304	.243
NANCY - NTR6	.425	.357	.334
LOWER SHEEP - LTR9	.258	.266	.182

1/ The units of soil erodibility are $\frac{\text{ton}\bullet\text{acre}\bullet\text{hour}}{\text{hundreds of acre}\bullet\text{foot}\bullet\text{tonf}\bullet\text{inch}}$

Table 3.12.--Cover-management factor values by data from rainfall simulation and by subfactor procedure of Dissmeyer and Foster (1981).

					COVER-MANAGEMENT FACTORS	
					SIMULATION	SUBFACTOR
PLOT[1/]	A	R[2/]	K_L[3/]	LS	C_L	C_S
	T/A					
REYNOLDS CREEK						
CLIPPED:						
FBR3	.242	92	0.326	0.2673	0.033	0.041
FBL3	.218	85	0.326	0.2807	0.031	0.041
FBR9	.181	86	0.243	0.6360	0.013	0.007
FBL9	.763	86	0.243	0.6653	0.052	0.041
NBR6	1.204	85	0.334	0.3907	0.109	0.024
NBL6	1.549	82	0.334	0.464	0.122	0.022
LBR9	0.023	86	0.182	0.5885	0.002	0.005
LBL9	0.040	88	0.182	0.7254	0.003	0.002
GRAZED:						
FGR3	.130	74	0.326	0.1984	0.030	0.024
FGL3	.203	80	0.326	0.2163	0.040	0.022
NGR6	.304	90	0.334	0.4983	0.020	0.011
NGL6	.155	88	0.334	0.4472	0.012	0.010
LGR9	.024	80	0.182	0.7459	0.002	0.011
LGL9	.072	82	0.182	0.7152	0.006	0.012
UNGRAZED:						
FUR3	.013	64	0.326	0.1984	0.003	0.010
FUL3	.018	70	0.326	0.2163	0.004	0.012
NUR6	.035	84	0.334	0.3301	0.004	0.011
NUL6	.055	84	0.334	0.3598	0.005	0.013
LUR9	.008	76	0.182	0.7051	0.001	0.005
LUL9	.003	82	0.182	0.7459	0.001	0.003

1/ Plot Designation-FIRST DIGIT: F is Flats, N is Nancy, L is Lower Sheep; SECOND DIGIT: T is tilled, B is clipped bare, G is grazed, and U is ungrazed; THIRD DIGIT: R is right plot and L is left plot of pair; and FOURTH DIGIT: number is approximate slope in percent.

2/ The units of simulated rainfall erosivity are $\frac{\text{hundreds of foot•tonf•inch}}{\text{acre•hour}}$ see (Foster et al. 1981).

3/ The units of soil erodibility are $\frac{\text{ton•acre•hour}}{\text{hundreds of acre•foot•tonf•inch}}$

snowmelt associated runoff accounts for over 90 percent of the sediment yields at the Reynolds Creek Outlet station, a few thunderstorms have caused highly visible erosion on small areas. Over the long-term, severe thunderstorms are infrequent and are usually limited to only a few square miles.

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Chapter 4

WATER QUALITY

GORDON R. STEPHENSON, Geologist

Chapter 4

WATER QUALITY

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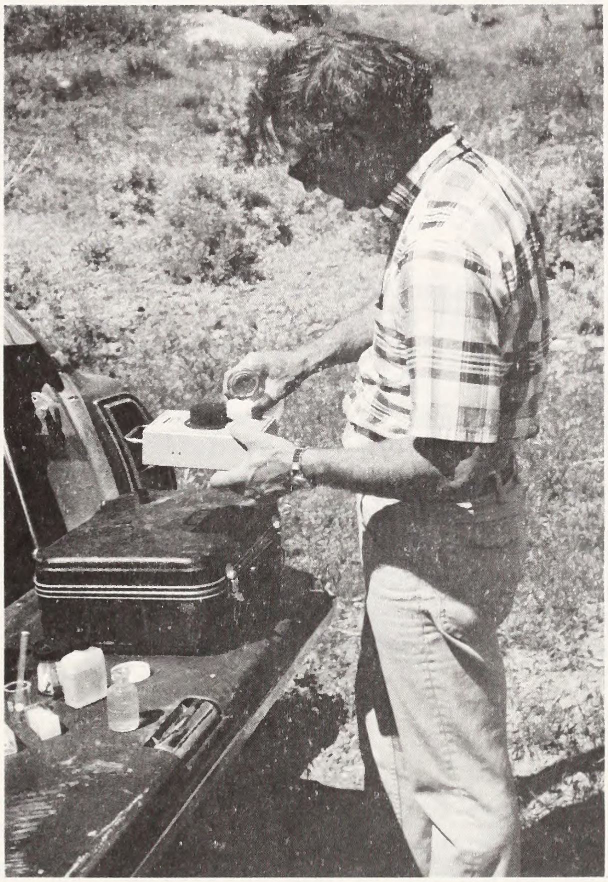


On-site Water Quality Analysis

INTRODUCTION

Water quality investigations at the Northwest Watershed Research Center were initiated in 1972 at the request of BLM for needed information on assessing potential water quality impacts associated with rangeland livestock operations. The need arose primarily out of federal laws requiring Environmental Impact Statements to be written for grazing allotments and for developing new allotment management plans. Because of the hydrologic facilities available, the Research Center offered an excellent opportunity for evaluation of water quality impacts associated with rangeland management practices. Water quality parameters, related to grazing management practices and rangeland hydrologic characteristics, were measured at monitored streamflow sites on the Reynolds Creek Watershed and satellite area.

For this study, attempts are made to evaluate the effect management practices---cattle grazing operations, irrigation, etc.,---have on the quality of streamflow. The effect naturally occurring phenomena have on quality of streamflow is also determined. The results of this work will aid in the development of better management practices through the identification and quantification of nonpoint sources of pollution on rangeland. With a better understanding of the magnitude and scope of water quality parameters for rangelands, the presence or absence of a water quality problem can be determined. The source data can provide insight into management practices and their effects on water quality. It is only through the application of basic data to the development of improved management practices that downstream water quality can be improved.

Objectives

The general objective of this research is to determine the water quality characteristics of streamflow on the Reynolds Creek Watershed and satellite area. Specific objectives are to determine water quality characteristics as influenced by: 1) livestock operations under various management practices; 2) irrigation return flow; and 3) natural soil, geologic, and vegetative conditions. Areas of nonpoint source pollutants are also determined and recommendations given for improved management practices.

Scope of This Investigation

This report is a summary of investigation of the water quality characteristics of the streams of the Reynolds Creek Watershed and satellite area. The research was initiated by ARS at the request of BLM through cooperative research agreements. Water samples were collected to determine the physical, chemical, and biological properties on regular schedules and according to climatic and land use conditions. A summary of data collected from all sites located on Figures 4.1 and 4.2 during the course of this investigation are given in Vol. III., Section D of this report.

Description of Study Areas

Reynolds Creek Watershed

The Reynolds Creek Experimental Watershed, Figure 4.1, located in Owyhee County, southwest Idaho, encompasses 57,728 acres and ranges in elevation from 3,600 to 7,390 feet, msl. Hydrologic investigations have been conducted by the Agricultural Research Service on this watershed since 1961. Streamflow is measured at the watershed outlet and at major tributaries by permanent structures. Precipitation and other climatic parameters have been measured continuously throughout the watershed.

The watershed is predominantly sagebrush rangeland, typical of the intermountain west, where cattle operations are the major industry. Approximately 2,000 acres of cultivated fields are irrigated by streamflow for hay production.

Soils of the watershed are mostly residual, being developed from volcanic rock, granite, and lake sediment parent material. Soil thickness and horizon development vary directly with elevation, slope, aspect, and climatic conditions.

The vegetative cover on the rangeland portion of the watershed is dominated by sagebrush with an understory of assorted grasses. Intermittent stands of Douglas fir and Aspen occur throughout the higher elevations, while permanent irrigated hay fields occur throughout the valley floor. Canopy cover on the rangeland varies from 0 to 75 percent.

Average annual precipitation varies from less than 10 inches at lower elevations to greater than 40 inches at the higher elevations. The majority of the total precipitation falls as snow.

Satellite Area

The Boise Front satellite study area, Figure 4.2, is located approximately 5 miles northeast of Boise at elevations ranging from 1,000 to approximately 3,000 feet, msl. The area consists of 15,740 acres of rangeland within the Lucky Peak Resource Management Unit divided into an 8-pasture, 4-year rest rotation grazing system. The unit is also the winter browse area for the largest deer herd in Idaho. Streamflow is measured on the major streams by permanent structures. Precipitation and other climatic parameters are measured throughout the study area. Precipitation varies from less than 10 inches per year to greater than 30 inches. Vegetation consists mostly of sagebrush, bitterbrush, and an understory of assorted grasses. Soils are mostly coarse, sandy and silty loams, developed from granite and lake sediment sources. Aspects are mainly to the south.

Locations of the water quality sampling sites are given in Figure 4.1 for the Reynolds Creek Watershed and in Figure 4.2 for the Boise Front satellite study area. Table 4.1 gives the sampling record and characteristics for all the sites. Twenty-three water quality sampling sites were established along Reynolds Creek and its tributaries. The sampling sites were chosen to best show the variations in water quality related to different land use and management practices.

Four sites were established along streams within the rest rotation pastures on the Boise Front satellite area. The data collected from these sites reflect the management and use pattern within these pastures.

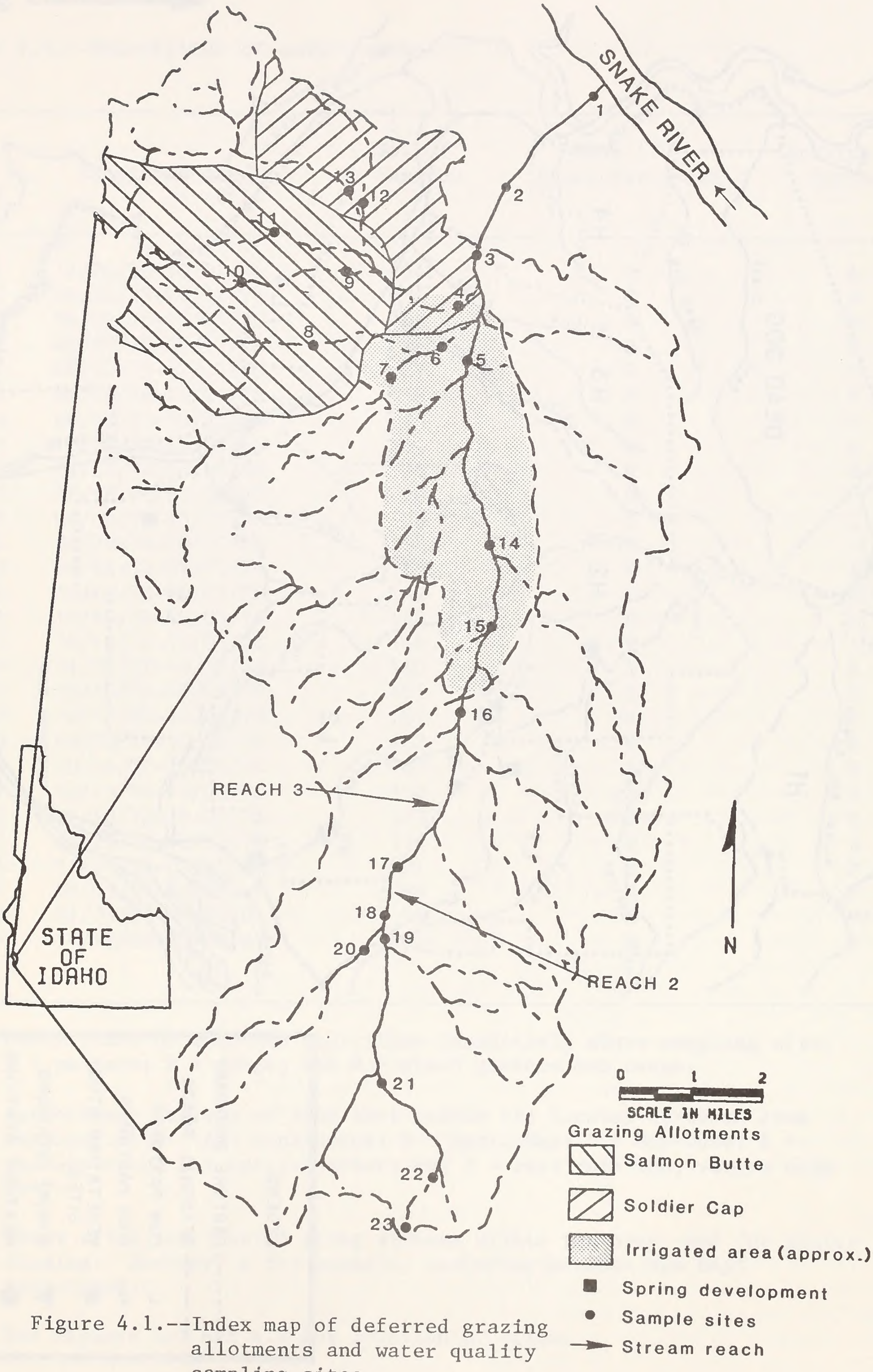


Figure 4.1.--Index map of deferred grazing allotments and water quality sampling sites.

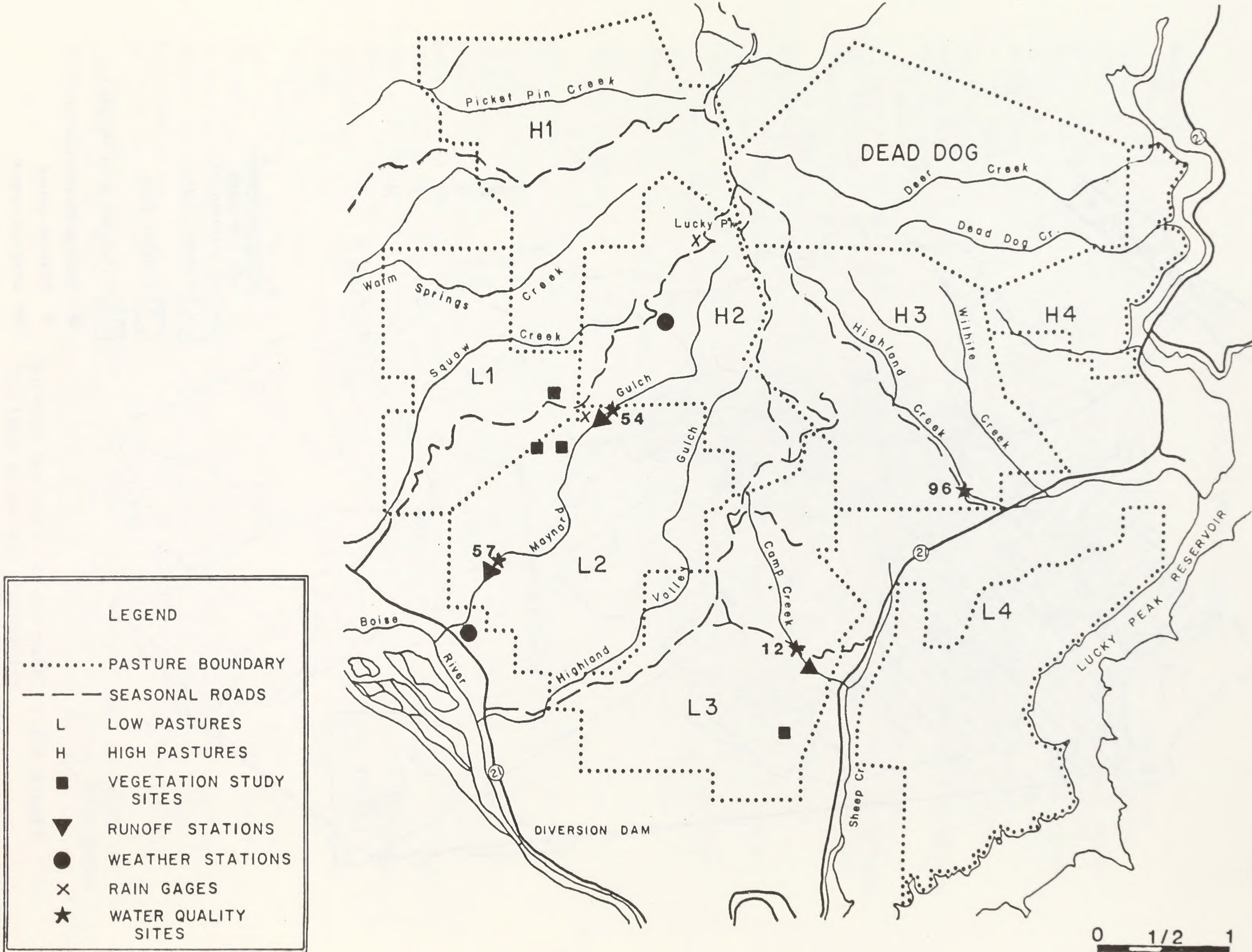


Figure 4.2.--Boise Front Satellite Study Area

Table 4.1.--Description of sample sites.

Site No. (++)	Sample Record	No. of Samples	Site (*) Characteristics	Grazing (+) Period
1	11/26/73-10/01/75	54	P	A
2	11/26/73-10/01/75	51	R	E
13	04/22/75-10/03/78	65	R	B
12	05/27/75-07/17/78	25	R	B
11	06/10/75-07/05/78	27	R	C
24	04/19/76-10/01/78	38	R	C
9	06/16/75-10/03/78	45	R	C
3	10/19/72-10/03/78	169	M	A
4	04/23/74-10/03/78	128	R	E
10	06/16/75-07/05/78	26	R	C
8	04/08/75-10/03/78	54	R	C
6	04/29/74-10/03/78	118	M	A(**)
7	04/14/74-07/05/78	35	M	A(**)
5	10/19/72-10/03/78	169	P	A(**)
14	10/19/72-10/03/78	128	P	A(**)
15	10/19/72-10/03/78	160	P	A(**)
16	04/23/74-10/03/78	140	R	E
17	10/18/72-10/03/78	161	R	E
20	10/18/72-10/03/78	157	R	D
19	04/23/74-10/03/78	142	R	D
18	10/18/72-10/03/78	143	R	D
21	12/19/72-10/03/78	154	R	D
22	12/10/72-10/03/78	123	R	D
23	01/29/73-10/03/78	111	R	D
54	11/15/76-07/21/81	121	R	F
57	04/05/77-06/22/81	89	R	F
12	04/05/77-06/22/81	55	R	F
96	11/15/76-09/28/81	162	R	F

(*) Description of land use activities immediately above sampling site: P = pasture; R = range; and M = mixed pasture and range.

(+) Approximate periods of time that cattle are located upstream from sampling site: A = continuous; B = April-May; C = May-June; D = June-October; E = April-October; and F = rest rotation, varies each year.

(**) These sites are located along streams within pastures used for winter feeding. However, a few animals, including horeses are kept year-round.

(++) See Figures 4.1 and 4.2 for location of sites.

SOURCES OF NONPOINT POLLUTION ON RANGELAND STREAMS

Natural Background

In order to determine the effect various management practices may have on the quality of runoff from rangeland ecosystems, the quality of streamflow from "natural" (ungrazed or unmanaged) conditions should be determined. Unfortunately, we did not have "natural" areas where water quality parameters could be evaluated. The best information available as a part of this evaluation was to determine the quality of streamflow at various sites during the time of year livestock were not grazing. Most variables measured during this period relate to changes in natural processes such as geologic erosion as a function of climatic, vegetative, soil, geologic and hydrologic conditions.

The grazing season on most rangeland runs from early April until mid-October. By using the October through April time period, when livestock are not on the range, for selected sites within the different rangeland grazing systems, estimates of background concentrations may be determined. Table 4.2 gives data for three selected sites for the October through April time period on the Reynolds Creek Watershed for the period of record. Sampling Sites 17, 21, and 22, all located within rangeland pastures (Figure 4.1), are used to determine background concentrations for key parameters. By close examination of the data given in Table 4.2, it is clear that the natural processes at work in these rangeland areas are not resulting in contributions to nonpoint source pollution. As the cattle are removed during October, key indicators of their presence, such as fecal coliform bacteria, soon revert to a baseline level. Estimates of background levels can be determined mainly during January-March when extraneous input has generally been removed. Figure 4.3 shows that fecal coliform concentrations are high when the cattle are removed in early October, but the concentrations are reduced as the coliforms are generally flushed from the channels during normal streamflow. High concentrations of fecal coliforms may occur during major runoff events for several months. This is the result of fecal coliform survival and regrowth in the organic layer on the streambottom sediments, and resuspension as the streambottom is disturbed by increased velocity during increased streamflow. Specific investigations of this phenomena are discussed more thoroughly in a later segment of this report.

As noted in Figure 4.3, fecal coliform concentrations for most sites for most years have averaged near zero by April, and do not respond to increased streamflow. By this time of year most colonies have died off or have been flushed from the streambottom sediments. In some cases, a continuing source of fecal coliform input from fecal material may exist and regrowth may occur as spring and summer temperatures increase. The longevity and regrowth of organisms from these sources was investigated and results are given later.

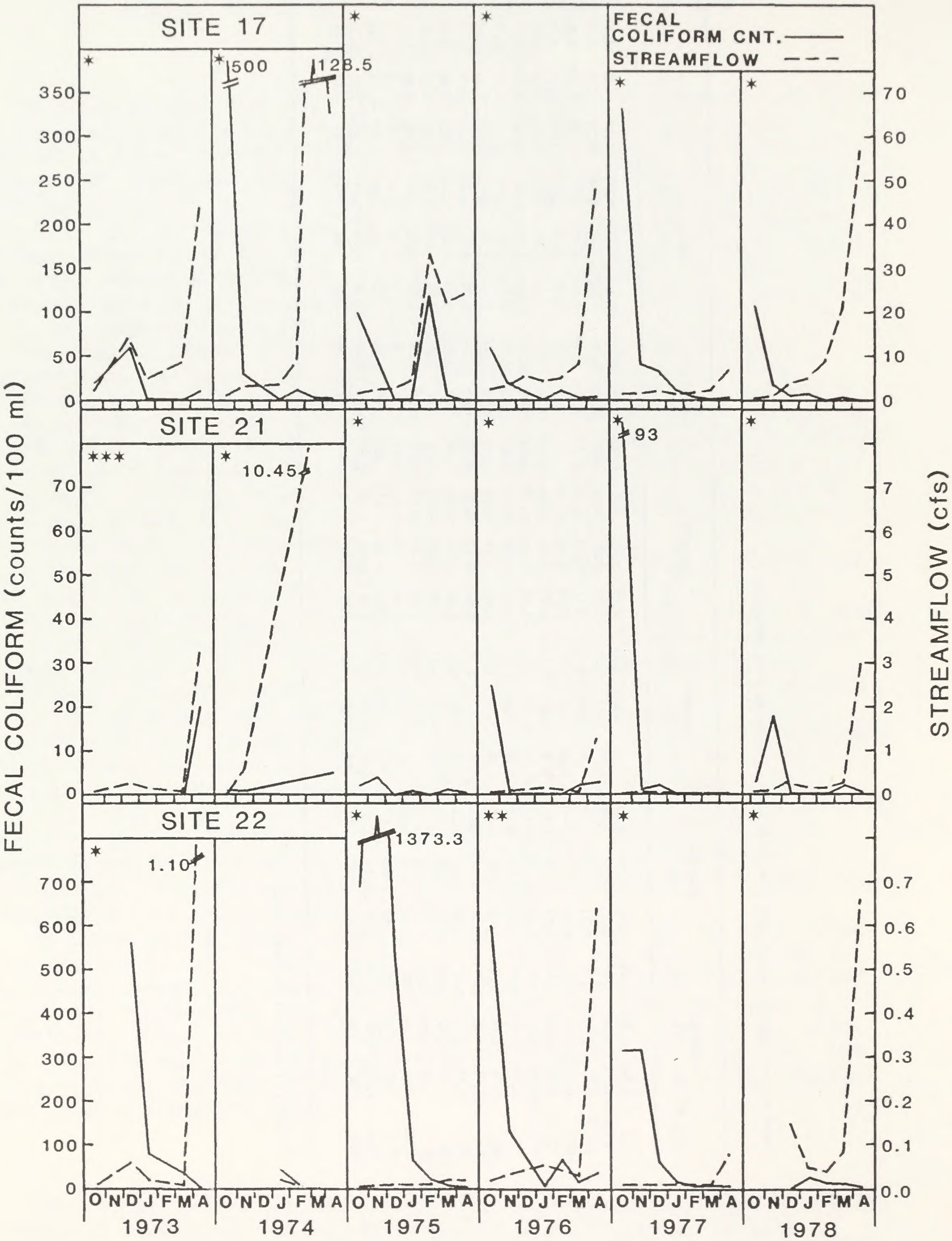
Grazing

The overall effect grazing has on the quality of streamflow during the course of this study was reflected mainly in bacterial variations. Chemical and suspended sediment variations failed to show any definite relationship between overall grazing practices and water quality. At all sites where water quality data were collected, however, one significant

Table 4.2.--Nongrazing season data from three sites on Reynolds Creek Watershed.

	October			November			December			January			February			March			April		
Site #[1/]	17	21	22	17	21	22	17	21	22	17	21	22	17	21	22	17	21	22	17	21	22
COD	5.38	4.25	8.50	5.50	5.33	9.50	7.00	3.50	8.50	4.14	6.75	6.60	14.85	4.00	6.00	13.08	20.00	14.00	10.00	13.00	10.67
TOT P	0.07	0.04	0.17	0.05	0.04	0.05	0.09	0.12	0.04	0.05	0.07	0.04	0.05	0.05	0.04	0.13	0.12	0.04	0.16	0.22	0.04
ORG N	0.21	0.18	0.74	0.16	0.17	0.16	0.32	0.39	0.17	0.13	0.22	0.15	0.11	0.09	0.21	0.29	0.22	0.16	0.38	0.38	0.20
BOD	0.50	--	--	0.00	--	--	2.80	3.00	--	1.33	4.00	4.00	--	--	--	0.67	2.00	2.00	1.00	6.00	2.00
DO	8.47	8.83	7.30	9.25	10.00	7.50	9.10	8.90	10.00	9.13	9.50	8.06	10.00	11.00	8.10	9.69	9.69	8.19	8.00	8.80	8.67
HCO_3	120.40	55.06	35.09	98.38	47.59	18.91	99.65	38.44	20.74	91.83	43.02	22.43	80.74	45.76	21.97	77.68	44.34	26.04	61.50	28.83	33.15
Cl	1.54	0.09	0.36	1.06	0.36	0.18	1.30	0.00	0.00	0.89	0.09	0.14	1.83	0.71	0.36	2.53	0.47	0.59	0.35	0.09	0.35
SO_4	4.16	8.89	0.96	4.08	7.84	2.16	6.24	7.45	3.12	4.88	6.91	2.69	4.72	6.72	2.64	3.67	5.43	2.55	2.40	2.39	2.73
Ca	19.91	12.58	2.51	17.59	11.22	3.81	17.57	9.42	3.71	16.50	10.17	4.01	14.47	11.02	4.01	14.22	9.81	4.47	11.86	6.56	6.94
Mg	8.43	2.77	1.64	6.62	2.27	0.85	7.25	1.89	0.97	6.28	2.28	1.07	5.80	2.07	1.03	5.15	2.22	1.29	3.89	1.06	3.15
Na	5.05	5.00	4.03	6.84	4.68	2.99	7.05	4.02	3.11	6.82	4.60	3.49	6.48	4.60	3.34	6.21	4.69	3.53	5.28	3.74	3.85
K	1.76	0.78	0.98	1.27	0.65	0.59	1.17	0.98	0.39	1.11	0.78	0.55	1.17	0.39	0.59	1.18	1.18	1.68	1.18	0.89	0.66
F Col	161	17	474	39	5	814	24	1	243	4	1	41	31	0	17	2	2	12	2	3	7
E C	187	95	59	152	82	41	157	76	43	156	79	47	129	72	40	120	73	39	97	45	42
Flow	1.31	0.02	0.01	2.18	0.11	0.01	5.07	0.05	0.05	3.99	0.08	0.03	12.38	0.07	0.03	23.21	0.09	0.03	41.47	2.37	0.50
TDS	157	106	60	125	98	45	185	93	53	173	102	58	144	95	50	135	86	47	99	49	49

[1/] Note site locations in Figure 4.1.


SITE 17
SITE 21
SITE 22
FECAL COLIFORM CNT.
STREAMFLOW
FECAL COLIFORM (counts/100 ml)
STREAMFLOW (cfs)
500
128.5
10.45
93
1.10
1373.3
O N D J F M A
1973
1974
1975
1976
1977
1978

factor was evident. Immediately or very soon after livestock entered the area above the site, bacterial concentrations increased. Likewise, following removal of the livestock, the bacterial concentrations declined. Evaluation of the impacts individual grazing management practices have on water quality will be covered in a later section. Specific discussion of the relationship of grazing and sediment production is discussed later in this chapter and under the Erosion and Sediment chapter of this report.

Irrigation Return Flow

Approximately 2000 acres of pasture land are irrigated in the Reynolds Creek watershed (Figure 4.1). Irrigation return flow has an impact on the quality of streamflow along Reynolds Creek, especially during the late summer-early fall.

The impact of irrigation on the quality of Reynolds Creek streamflow can be seen by looking at the sodium adsorption ratio (SAR) versus specific conductance (EC) data. Figure 4.4 gives these relationships for site No. 5 on Reynolds Creek within the irrigated area. This particular kind of plot reveals whether the water contains hazards pertaining to alkalinity and/or salinity. It is obvious from the data on Figure 4.4 that the impact of irrigation on Reynolds Creek water is related to salinity, not alkalinity. The increased salinity occurs mainly during the late summer-fall irrigation season as the streamflow is quite low and composed mostly of return flow from the irrigated fields of saline soils. The low salinity of April-June, as noted in Figure 4.4, is caused by dilution from the snowmelt runoff from the higher elevations. The December-March readings are probably near normal for this site. A more detailed analysis of the chemistry of the return flow will be given in a later section of this report.

Other

Several other potential nonpoint sources of pollution to rangeland streams should be recognized even though these were not found to occur in this investigation. In some rangeland areas the effects of past mining practices have resulted in degradation of stream quality. Mercury was used extensively in the late 1800's and early 1900's to settle out heavy metals, such as gold. Today it is often found in the alluvial channels, downstream from mill sites in many of the old mining areas. Acidic waters often result from seepage of mine dumps associated with sulfide enriched mineral deposits.

Certain recreation activities can have an impact on the quality of streamflow of rangeland streams. Sediment produced by off-road recreational vehicles used indiscriminantly, can reduce quality of streams if overland flow from these areas goes directly into the streams. A recent study in Montana (Temple et al. 1982) has shown that shallow burial of feces, a practice often recommended to backcountry recreationists, does not result in quick destruction of intestinal pathogens.

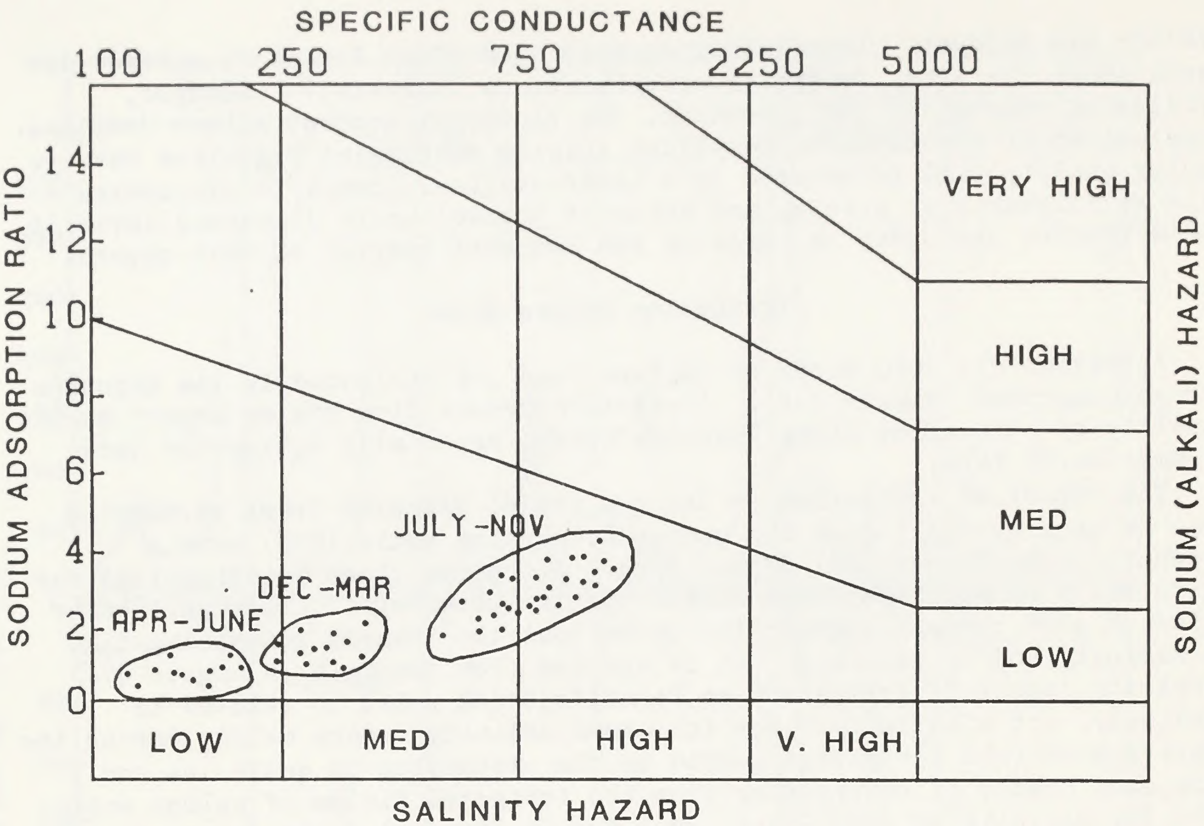


Figure 4.4.--Relationship of Salinity and Alkalinity hazard in Reynolds Creek Streamflow.

INDICATORS OF RANGELAND NONPOINT POLLUTANTS

The potential impact that grazing livestock operations (along with the confined winter feeding) have on rangeland streams appears principally in the form of nutrients, fecal coliforms, and sediment.

Nutrients from livestock are generally in the form of nitrogen and phosphorous. Nutrient loading in streams can cause a rapid increase in aquatic plant life such as algae, resulting in eutrophication.

Other chemical constituents are those which ionize and occur in the dissolved state. Salinity, aklalinity, and sulfates are frequently assessed from anion and cation measurements. Total dissolved solid (TDS) assessment gives an approximation of the amount of ions in solution. Sodium adsorption ratio (SAR) is an index of the sodium (alkalinity) hazard and is especially important when the stream water is used for irrigation.

Suspended sediment, or suspended particulate matter, is a measure of the inorganic material in suspension. It does not include bedload.

Bacterial organisms are usually used as an indicator of sources of pollution. The fecal coliform group, when occurring in appreciable concentrations, may indicate a disease producing potential in the water sample.

Chemical Constituents

The major departure in chemical constituents from natural background levels was evaluated in respect to irrigation return flows. Irrigation on the lower reaches of the Reynolds Creek watershed is the major cause of elevated levels of the major dissolved constituents which occur during mid to late summer.

To illustrate these changes, data from two sites are used--site No. 17 on open range with no irrigation return flow and site No. 5 in the irrigated area of the watershed where irrigation return flow dominates during the summer. Figure 4.5 gives concentrations of the major chemical constituents for these two sites (see Figure 4.1 for the location of these sites).

To show changes in chemical concentration due to irrigation return flow, data from April through October for 1972 through 1978 are used. Figure 4.5 shows the increase in concentrations occurring at the irrigated area, site No. 5, as compared with the rangeland area, site No. 17. One reason for this difference is that, because of longer time in residence, chemical concentrations normally increase downstream. However, the data do not indicate a gradual downstream increasing trend in concentrations; rather, a rapid increase occurs as soon as the stream enters the irrigated area. The major change occurs in July, when return flow is maximum, and the most significant ions are calcium, magnesium, sodium, and chloride. This is the result of these soluble ions being flushed from the irrigated fields. Sulfate also increases considerably, which results from the change in geologic material (evaporites in lake sediments) over which the stream flows.

The second explanation for increased chemical concentration is the decreasing streamflow during the irrigation season, making the ionic concentrations per volume of water higher. Streamflow in the lower reaches of the watershed during late summer and early fall originates

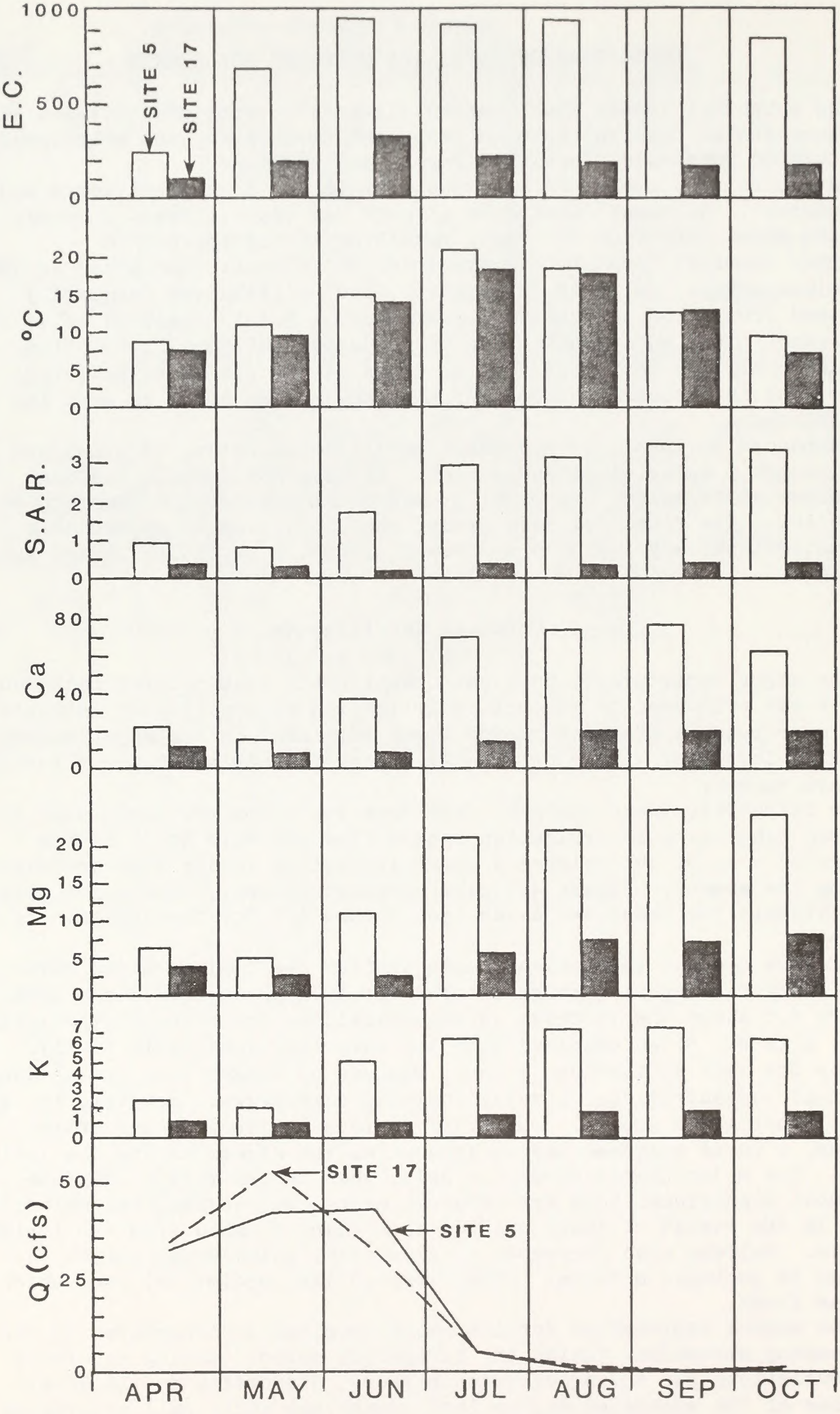


Figure 4.5.--Variations in major chemical constituents (mgl) and streamflow: sites 5 and 17, Reynolds Creek.

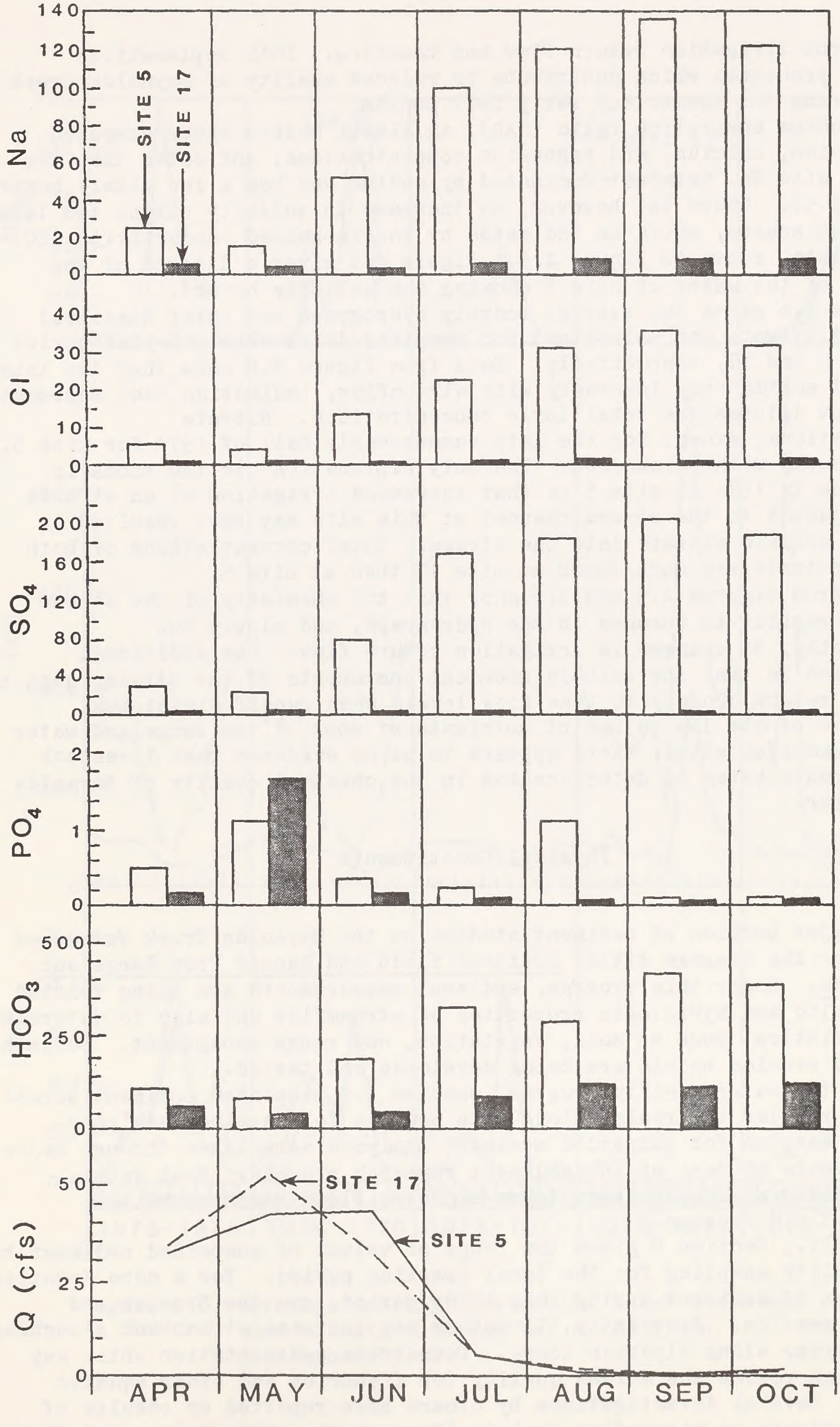


Figure 4.5.--Continued.

mainly from irrigation return flow and baseflow. Both explanations describe processes which contribute to reduced quality of Reynolds Creek water during the summer and early fall months.

The sodium adsorption ratio (SAR), an alkali hazard index computed using sodium, calcium, and magnesium concentrations, indicates that the water at site No. 5 is not dominated by sodium and has a low alkali hazard (Figure 4.5). There is, however, an increase in salinity during the late irrigation season, which is indicated by the increased conductivity (EC) measurements, shown in Figure 4.5. Figure 4.4 gives a diagram of the analysis of the water at Site 5 showing the salinity hazard.

Figure 4.6 gives the average monthly hydrograph and total dissolved solid and nitrate concentrations for sampling dates over a 5-year period at sites 5 and 17, respectively. Data from Figure 4.6 show that the total dissolved solids vary inversely with streamflow, indicating that increased streamflow dilutes the total ionic concentrations. Nitrate concentrations, except for the late summer-early fall of 1974 for site 5, vary directly with streamflow. The only explanation for the anomalis occurrence in 1974 at site 5 is that increased irrigation of an alfalfa field adjacent to the stream channel at this site may have resulted in flushing soluble nitrate into the stream. Total concentrations of both TDS and nitrate are much lower at site 17 than at site 5.

Data from Figures 4.5 and 4.6 show that the chemistry of the stream responds rapidly to changes in the hydrograph, and slowly but consistently, to changes in irrigation return flow. One additional observation is that the soluble chemical components of the stream, such as nitrate, return closely to base flow levels when runoff diminishes.

Because of the low values of nutrients at most of the rangeland water quality sampling sites, there appears to be no evidence that livestock grazing contributes to deterioration in the chemical quality of Reynolds Creek water.

Physical Constituents

Sediment

The major portion of sediment studies on the Reynolds Creek Watershed fall under the program title, <u>Sediment Yield and Runoff From Rangeland Watersheds</u>. Under this program, sediment measurements are being related to hydraulic and hydrologic properties of streamflow and also to watershed characteristics, such as soil, vegetation, and range management. Sediment yield and erosion models are being developed and tested.

Under the water quality program, samples for suspended sediment were taken at regular intervals, along with samples for chemical analyses. Detailed samples for suspended sediment analyses were taken through major runoff events as part of the sediment research program. Most water quality sediment samples were taken at lower flows and augment the Sediment Yield Program.

Vol. III., Section D gives the range of values of suspended sediment by water quality sampling for the total sampling period. For a more detailed discussion of sediment during this study period, see the Erosion and Sediment section. Frequently, livestock may increase streambank sloughing as they graze along riparian zones. Downstream sedimentation which may result, can reduce the stream quality for fisheries and other aquatic habitat. Several investigations by others have reported on results of grazing effects on streamflow quality (Gary et al. 1983; Meehan and Platts

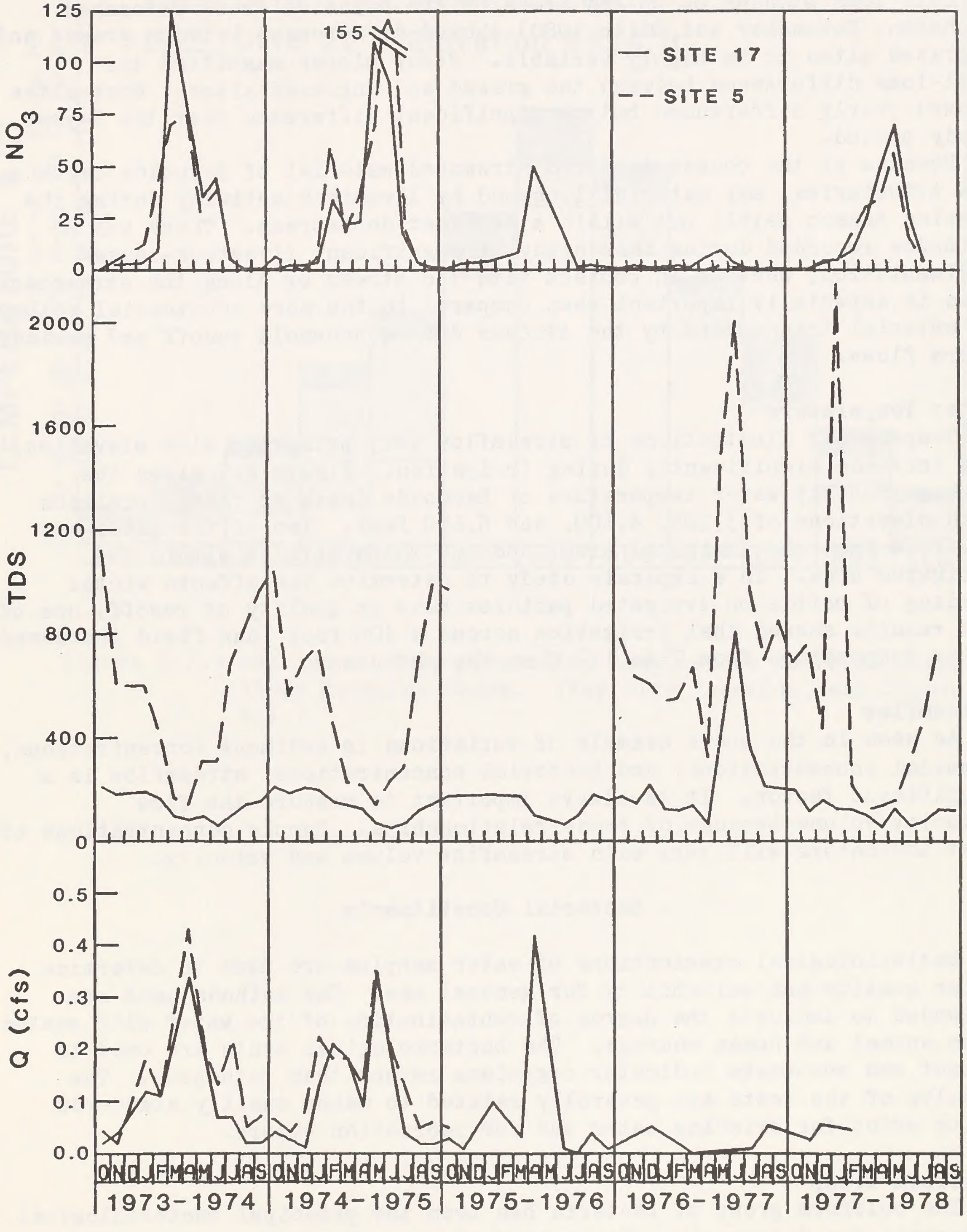


Figure 4.6.--Average monthly hydrograph, total dissolved solids and nitrate nitrogen for sites 5 and 17, 1973 through 1978.

1978; Ames 1977; Johnson and Moldenhauer 1970; Buckhouse, Knight and Scovlin 1977; and Buckhouse, Scovlin and Knight 1981).

Soil loss studies on upland areas of the Reynolds Creek Watershed (Johnson, Schumaker and Smith 1980) showed differences between grazed and ungrazed sites to be highly variable. Steep slopes magnified the soil-loss differences between the grazed and ungrazed sites. Most sites showed yearly differences but no significant difference over the 7-year study period.

Because of the coarse textured streambed material of Reynolds Creek and its tributaries, any material loosened by livestock activity during the grazing season settle out within a few feet downstream. There was no evidence recorded during this study of significant livestock-caused sedimentation, whether in contact with the stream or along the streambank. This is especially important when compared to the more substantial volumes of material transported by the streams during snowmelt runoff and periodic storm flows.

Water Temperature

Temperature fluctuations of streamflow vary primarily with elevation, but increase significantly during irrigation. Figure 4.7 gives the average monthly water temperature of Reynolds Creek at three locations with elevations of 3,705, 4,600, and 6,600 feet. Two of the sites are upstream from the irrigated area, and the third site is within the irrigated area. In a separate study to determine the effects winter feeding of cattle on irrigated pastures have on quality of runoff, one of the results showed that irrigation across a 400 foot long field increased water temperature from 7° to 11° C in May and June.

Streamflow

As seen in the above example of variations in sediment concentrations, chemical concentrations, and bacterial concentrations, streamflow is a significant factor. It is always important to measure the flow velocity/volume because of these relationships. Sample concentrations of most indicators will vary with streamflow volume and velocity.

Bacterial Constituents

Bacteriological examinations of water samples are used to determine water quality and suitability for general use. The methods used are intended to indicate the degree of contamination of the water with wastes from animal and human sources. The bacteriological tests are used to detect and enumerate indicator organisms rather than pathogens. The results of the tests are generally related to water quality standards which exist for drinking water and for recreation waters.

Coliform Group

The coliform group of bacteria has been the principal bacteriological indicator for determining the quality of water as it is made up of bacteria associated with feces of warm-blooded animals and with soil. The fecal coliforms, that portion of the coliform group originating in the intestine of warm-blooded animals and used principally in this investigation, are the best indicators of livestock contamination in natural waters.

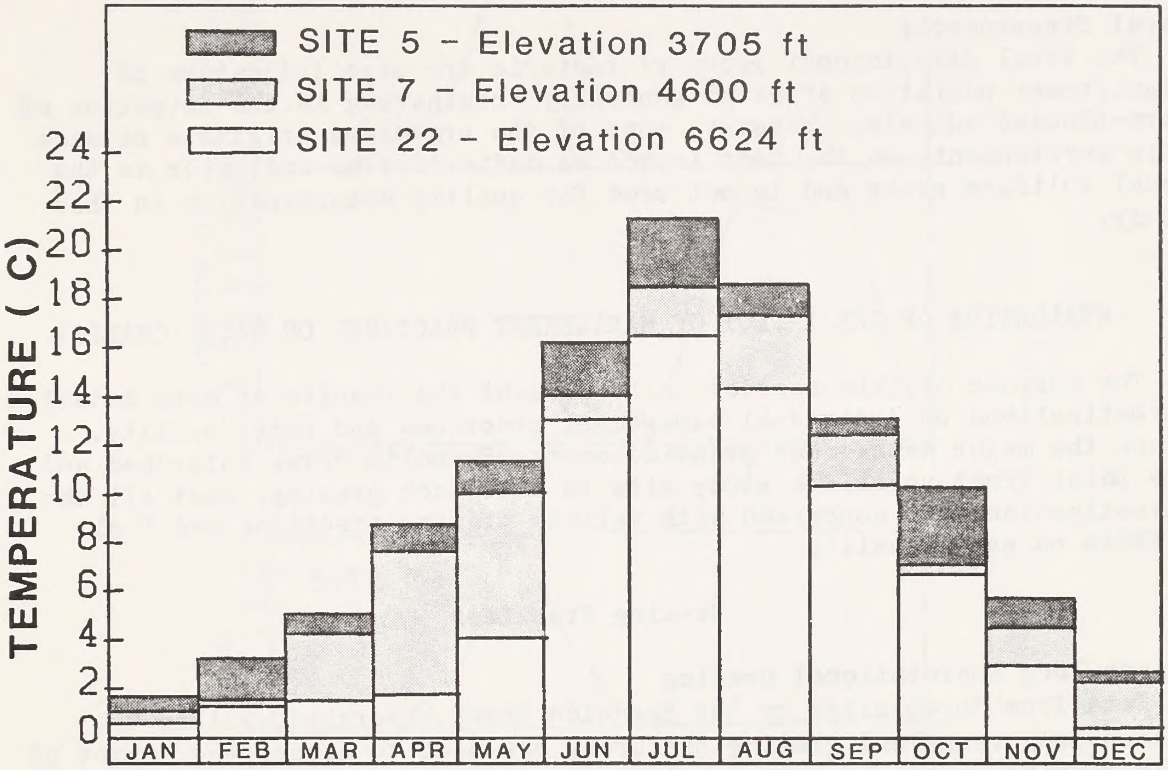


Figure 4.7.--Average monthly streamflow temperature at three sites along Reynolds Creek. (For site location, see Figure 4.1.)

Fecal Streptococci

The fecal streptococci group of bacteria are also indicators of significant pollution of water generally originating in the intestine of warm-blooded animals. However, some of the organisms originate outside this environment, so the test is not as definitive an indicator as the fecal coliform group and is not used for quality determination in this study.

EVALUATION OF THE IMPACT OF MANAGEMENT PRACTICES ON WATER QUALITY

The purpose of this section is to present the results of more detailed investigations on individual management practices and water quality. Since the major management practice on the Reynolds Creek Watershed and the Boise Front satellite study site is livestock grazing, most all the investigations are concerned with various grazing practices and their effects on water quality.

Grazing Practices

Season-long Nonrotational Grazing

Data from three sites on the Reynolds Creek Watershed, within the season-long rangeland grazing pastures, are used to assess the impact of this grazing system on water quality. Sites 22, 21, and 18, located along channel segments on open range with elevations of 6,624, 5,479, and 4,800 feet msl, respectively, are used for this evaluation (see Figure 4.1).

Under close examination of the data collected, none of the water chemistry indicators reflect any significant impact on the quality of streamflow at these three sites. The only significant indicator is fecal coliform, which is the one used here for evaluating the water quality impact of the season-long nonrotational grazing system.

Figure 4.8 gives variations in fecal coliform concentrations and the streamflow hydrograph for each of the three sites for the 1972-1978 period of record. The bacterial concentrations are plotted as average monthly concentrations for the period of record and the streamflow hydrograph is given for weekly averages in cubic feet per second.

Site 22 (Figure 4.8) is located on a small drainage in sagebrush rangeland, within a fenced area grazed by approximately 500 cattle from July through October. The number of cattle grazed may vary from year to year, depending on grazing conditions and operator's plans. The site is generally snow-covered from November through May.

The effect the presence of cattle has on bacterial concentrations of the stream at this site is quite pronounced. Fecal coliform concentrations increase rapidly as soon as cattle are moved into the area in early July, as seen in Figure 4.8, and remain high until after the cattle are removed.

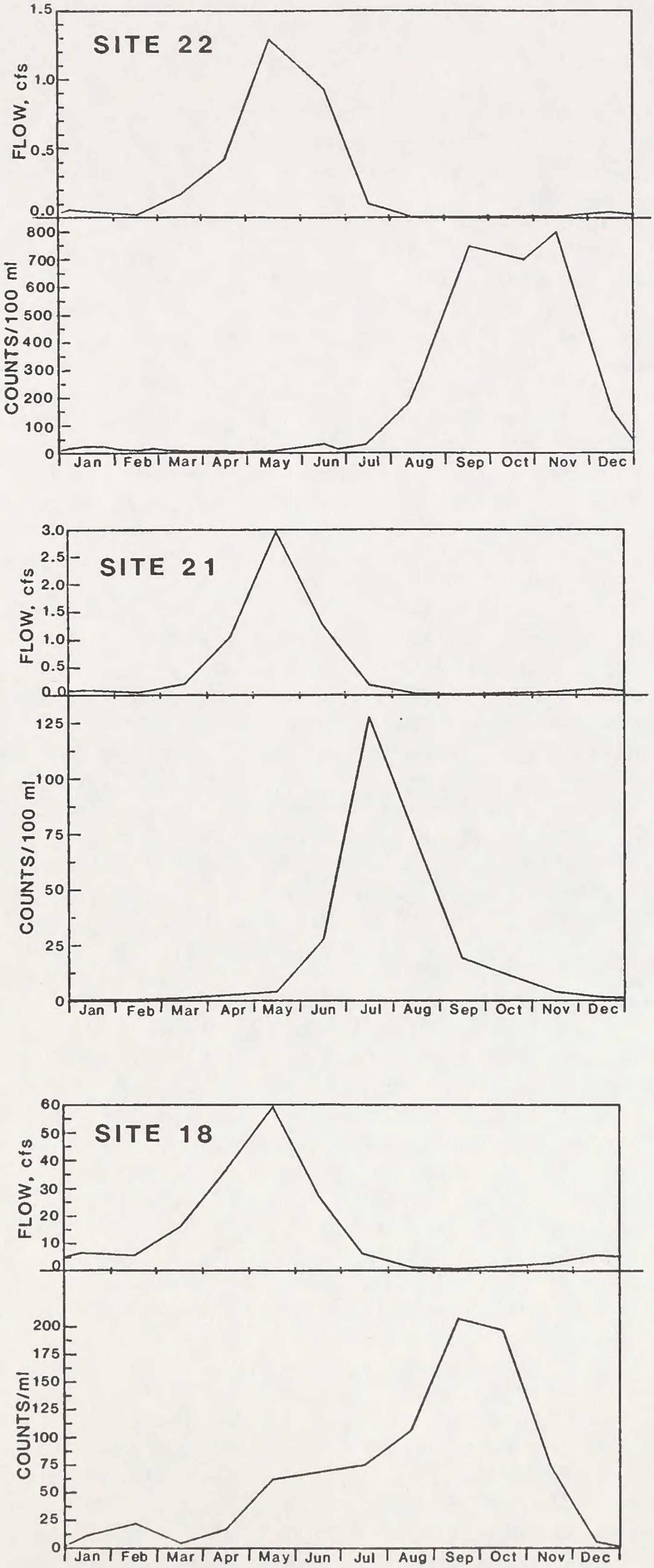


Figure 4.8.--Average monthly streamflow and fecal coliform content.

Peak streamflow, resulting from snowmelt, occurs during April-June and has little effect on concentrating bacterial colonies. The heavy snow cover probably prevents any transporting of bacteria from the soil surface by overland flow into the channels during the winter months to be carried away by spring runoff. Most of the fecal colonies, resulting from the previous year's grazing season, have been flushed out of the channel or died off by spring snowmelt time. A slight increase in fecal counts however, occurs in June, which is the result of these residual organisms being flushed from the bottom sediments and resuspended in the streamflow.

During dry years in late summer, such as 1973, 1974, and 1977, the stream at this site may dry up and stockwater is provided by a spring and pond. The bacterial concentrations remain high following recurrence of streamflow. In fact, the highest fecal counts are recorded soon after resumption of flow. The only other direct relationship between runoff and baterial concentrations at this site occurred prior to grazing in late March - early April 1975, during a warm, rainy period, resulting in increased flow. Again, residual organisms were resuspended as streamflow velocity caused disturbance of the bottom sediments.

After cattle are removed from the area in late fall, residual colonies remain high for nearly two months, as the streamflow flushes most of the colonies downstream. The colonies remain viable in the the organic matter of the bottom sediment well into the winter months, until further flushing and colder temperatures considerably reduce their numbers.

Site 21 is located in a narrow canyon near the center of a large grazing area in which over 900 cattle graze from June through September. The stream gradient is high and the channel very rough immediately above this site. The general bacterial and streamflow trends, Figure 4.8, are the same as for site 22, except considerably reduced in concentration. This reduction is probably the result of greater distribution of cattle as water sources are more plentiful than for site 22. Also, aeration, which "self-purifies" the water as the stream flows over rapids and small falls for approximately two miles upstream from the site, may cause further reduction of organisms.

Bacteria and streamflow data from site 18 (Figure 4.8) reflects a longer grazing season above this site than at the previous two sites. Although maximum concentrations occur at about the same time, several conditions within the area above this site cause periodic increases in bacterial concentrations not found at the previous sites. First, large stands of cottonwood trees occur along the channel where cattle congregate for shade. Concentrations of bacteria increase relative to this situation. Second, during fall roundup, cattle are concentrated in holding corrals adjacent to the channel just above this site and peak fecal coliform concentrations in the stream occur almost immediately. Approximately 1,000 cattle graze in the area above this site from late June to mid October.

Deferred Rotation Grazing System

The Bureau of Land Management's Reynolds Creek allotment management plan (USDI-BLM 1975) incorporates more detailed management into the grazing system on a portion of the Reynolds Creek Watershed. Prior to the application of this plan, the area received heavy use by 20 operators as cattle were allowed to graze from lower to higher elevations as the season progressed. The plan uses a deferred rotation grazing formula, designed

to improve range conditions and stabilize livestock production consistent with other multiple resource values. The allotment is broken up into seven fenced fields, with early spring grazing in three fields and deferred grazing in others until summer or early fall. These treatments will vary from field to field on a four-year rotational basis.

To determine the effect that a strict management plan such as this might have on the quality of streamflow, six sites were monitored in two fields during the grazing season. Again, fecal coliform concentrations were used as the water quality indicator. Sites 12 and 13 located in the Soldier Cap field, used for early spring grazing, and sites 8, 9, 10, and 11 are located in the Salmon Butte field, which is used for early summer grazing. Figure 4.1 gives location of these sites and the two allotment fields. Approximately 1,050 cattle, from five operators, are grazed in these fields during the allotted times before moving into adjacent fields. A small number of mule deer and approximately 32 wild horses also graze in the area.

The original allotment plan calls for grazing in the Soldier Cap field from approximately May 1 to May 15, and in the Salmon Butte field approximately, May 15 through June 15. A composite of the 116 samples collected at the sites in each allotment, is given in Figure 4.9. Fecal coliform bacteria is used to illustrate the changes. Samples were taken weekly from April through September for the four-year period, 1975-1978. Because of incomplete fencing during the first year (1975), the cattle were not kept strictly in their designated fields at all times. Bacterial indicator concentrations varied accordingly, which is evident from the fecal coliform data for 1975, Figure 4.9, as the cattle did not move out of the Soldier Cap pasture until late May. The bacterial concentrations for the Salmon Butte field show the effects of the cattle entering in early June instead of mid-May as scheduled. As seen in Figure 4.9, Soldier Cap allotment for 1975, no fecal counts were recorded from April 22 until approximately May 15. Concentrations were elevated and remained high through June 24. By July 7, the concentrations were nearly zero. For 1976-1978, the May 1 schedule for the Soldier Cap field was adhered to, which is reflected in sudden increases in fecal coliform concentrations in early May.

No fecal counts were recorded until June 3 in 1975 for the Salmon Butte allotment and started decreasing rapidly after June 24 (Figure 4.9). In 1976-1978, the June 1 schedule was followed.

On July 21, 1975, a high-intensity summer storm passed through this area, causing considerable runoff. As seen in Figure 4.9 for the Soldier Cap allotment, the flushing effect of the runoff resulted in concentrating the residual bacteria into the stream even though the cattle had been out of the area by as much as three weeks. Similar phenomena occurred in 1976, 1977, and 1978, only with lesser intesity, but the results varied from one stream channel to another. The result of bacteria remaining in stream bottom sediments for later flushing will be covered in a later section.

These data indicate that the introduction of cattle into these new management allotment fields, even for a short period of time, has a very sudden effect on bacterial quality of the streams. Bacterial concentrations in the streams are reduced rapidly after the cattle are removed, but residual colonies remain along the streambanks and in the stream bottom sediment and are subject to flushing and resuspension for some time afterward.

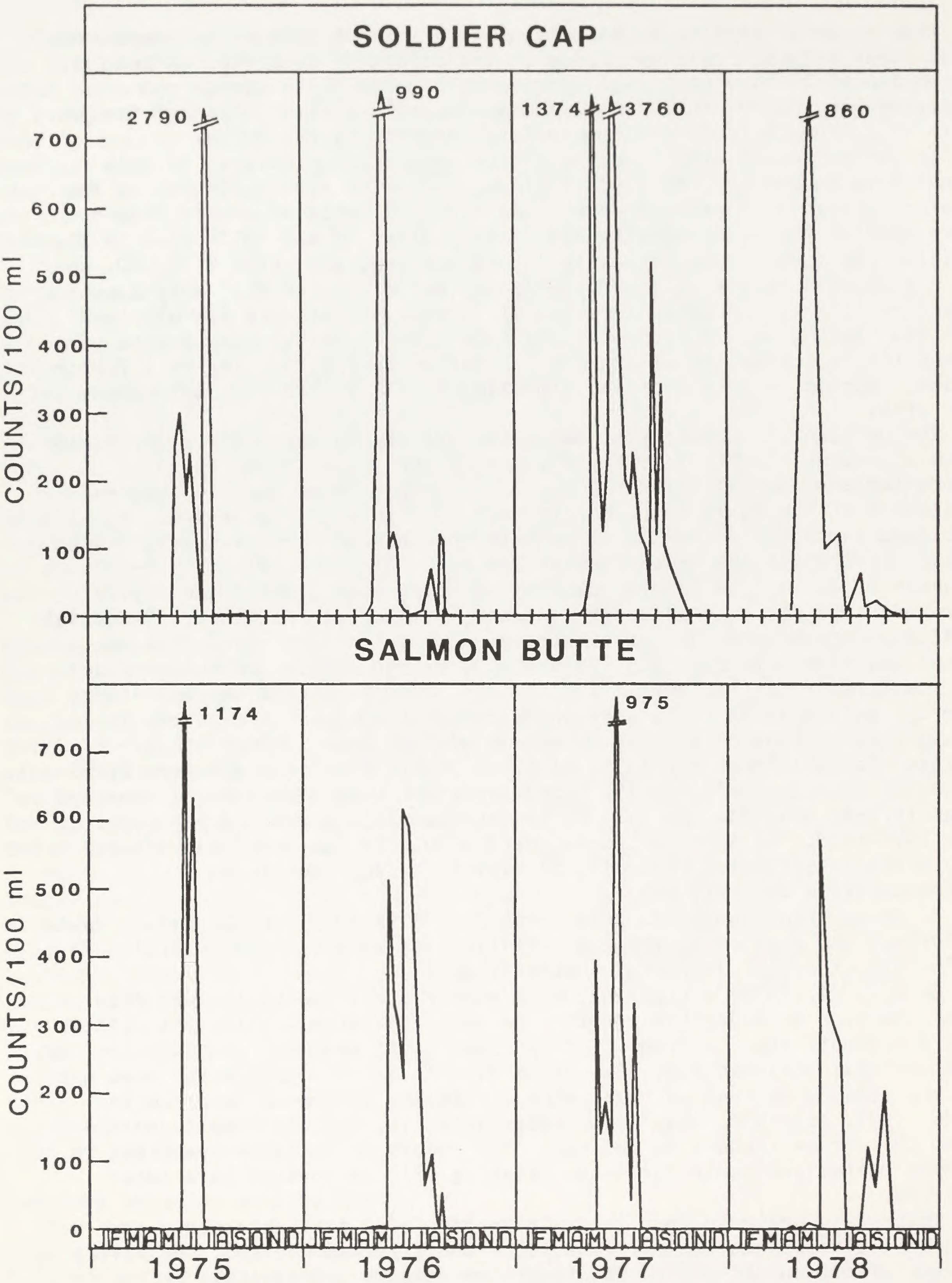


Figure 4.9.--Fecal coliform data for Soldier Cap and Salmon Butte pastures.

Rest Rotation Grazing System

Evaluation of the impact of rest rotation grazing management on the water quality of the stream was done on the Boise Front satellite study area, Figure 4.2. A detailed description of the area is given in the Introduction to this chapter. The grazing schedule for the four-pasture system is given in Table 4.3.

Water quality data were collected from streams in each of the pastures for 1978-1981. Sampling sites are located immediately upstream from continuous recording weirs. Intermittent streamflow occurs in most of the channels during the late summer in most years, resulting in movement of cattle between pastures by the operators. As a result, some overlapping of grazing between pastures occurs and is observed in the data.

Tables D.1-D.4, Vol. III., Section D, gives a statistical summary of the water quality data collected over the four-year period for the rest rotation system. Comparisons of all parameters analyzed can be made between years, and between pastures, as the cattle grazing schedule is rotated from year to year.

When comparing the data from Tables D.1-D.4, the most significant indicator of water quality variations continues to be the fecal coliform concentrations. The fecal coliform indicator relates directly to the presence of warm-blooded animals, mainly cattle, sheep, and deer, and reflects the grazing schedule of the rest-rotation management system. Other indicators, such as suspended solids and nutrients, show some variation between sites and between sampling dates, but are more frequently the result of runoff characteristics than the absence or presence of livestock.

Figure 4.10 gives the variation in fecal coliform concentrations over the sampling period for all four sites. A band of over 2,000 sheep pass through the Boise Front rest rotation pastures every spring and fall of each year. A deer herd in excess of 4,000 head winter in portions of the area each year. The rapid increases of fecal coliform concentrations in Figure 4.10 are the result of the presence of these animals (cattle, sheep and deer), with peak concentrations occurring when the different animal groups are present.

Table 4.4 gives the average fecal coliform concentration for the four sites for the four-year record. Each site reflects the water quality of the runoff from the individual grazing pastures within the rest-rotation system. During the years which cattle graze the individual pastures, the average fecal coliform concentration is usually the highest. In 1980, pasture L2, the Lower Maynard site, was grazed, but the stream was dry when the cattle were turned in, so no samples were taken. The cattle obtained water from spring flow developments. In 1981, pasture H2, Upper Maynard, was not scheduled for grazing, but had a very high fecal coliform average. The reason for this was that, because of low stream flow, gates between pastures were left open so cattle could move between pastures H3 and H2. Consequently, pasture H2 was grazed in 1981 even though the grazing schedule called for the pasture to be rested.

Winter Feeding Pastures

Figure 4.11 gives fecal coliform data from sites 3 and 5, reflecting the presence of cattle in winter feeding pastures. Cattle have access to Reynolds Creek for drinking water during the winter. These two sites are

Table 4.3.--Grazing schedule and type of management for Boise Front pastures.

Year	Pasture			
	High or Low, 1	High or Low, 2	High or Low, 3	High or Low, 4
1978	C Early rest (until seed ripe) (Graze Pickett Pin 4/1-5/8)	A Graze season long	D Rest season long (seedling establishment)	B Rest season long (for plant vigor)
1979	D Rest season long (seedling establishment)	B Rest season long	A Graze season long	C Early rest (until seed ripe)
1980	A Graze season long	C Early rest (until seed ripe)	B Rest season long (for plant vigor)	D Rest season long (seedling establishment)
1981 (1977)	B Rest season long (for plant vigor)	D Rest season long (seedling establishment)	C Early rest (until seed ripe)	A Graze season long

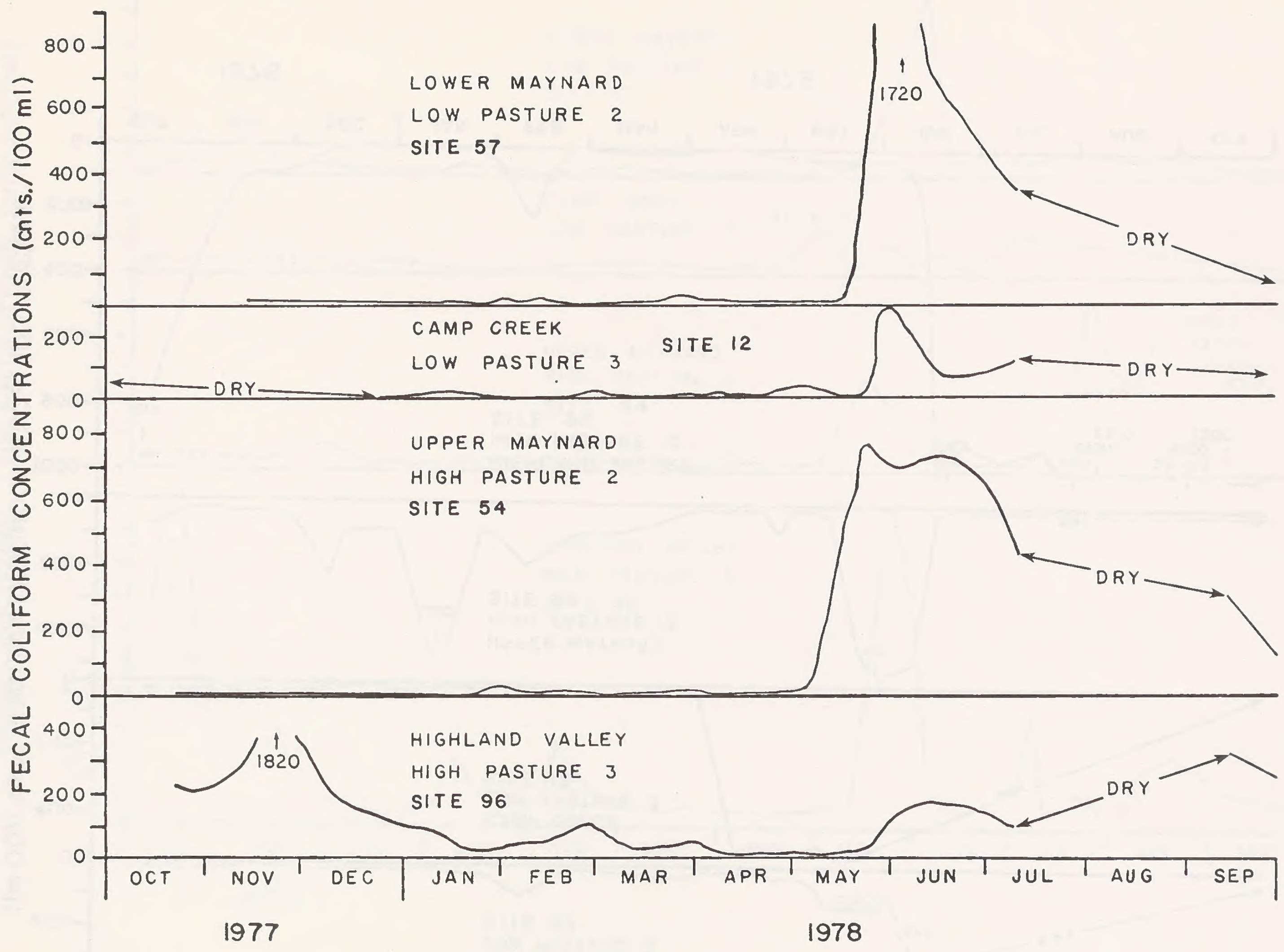


Figure 4.10.--Fecal coliform concentration, Boise Front study area. Reflects grazing of cattle, sheep, and deer.

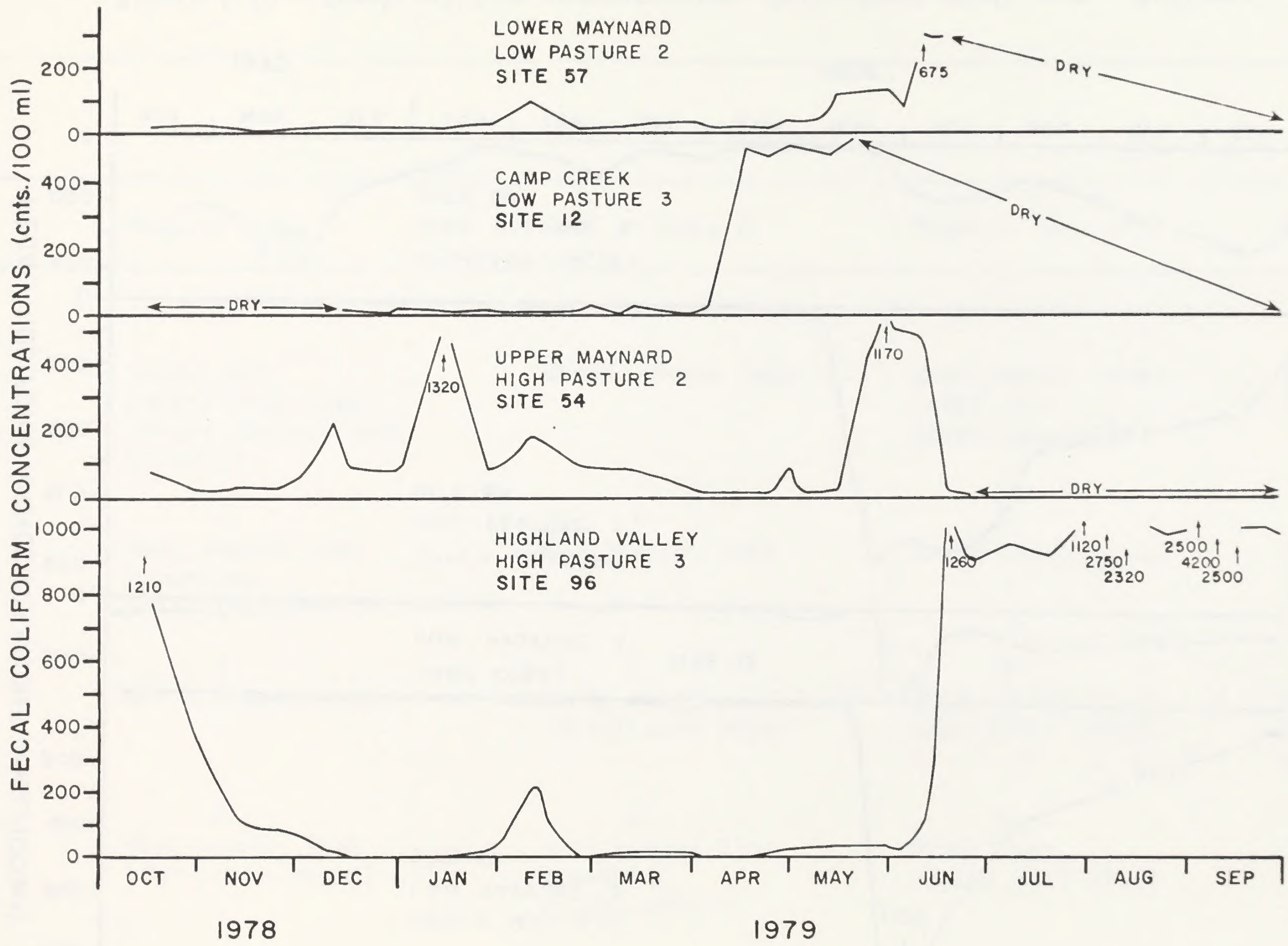
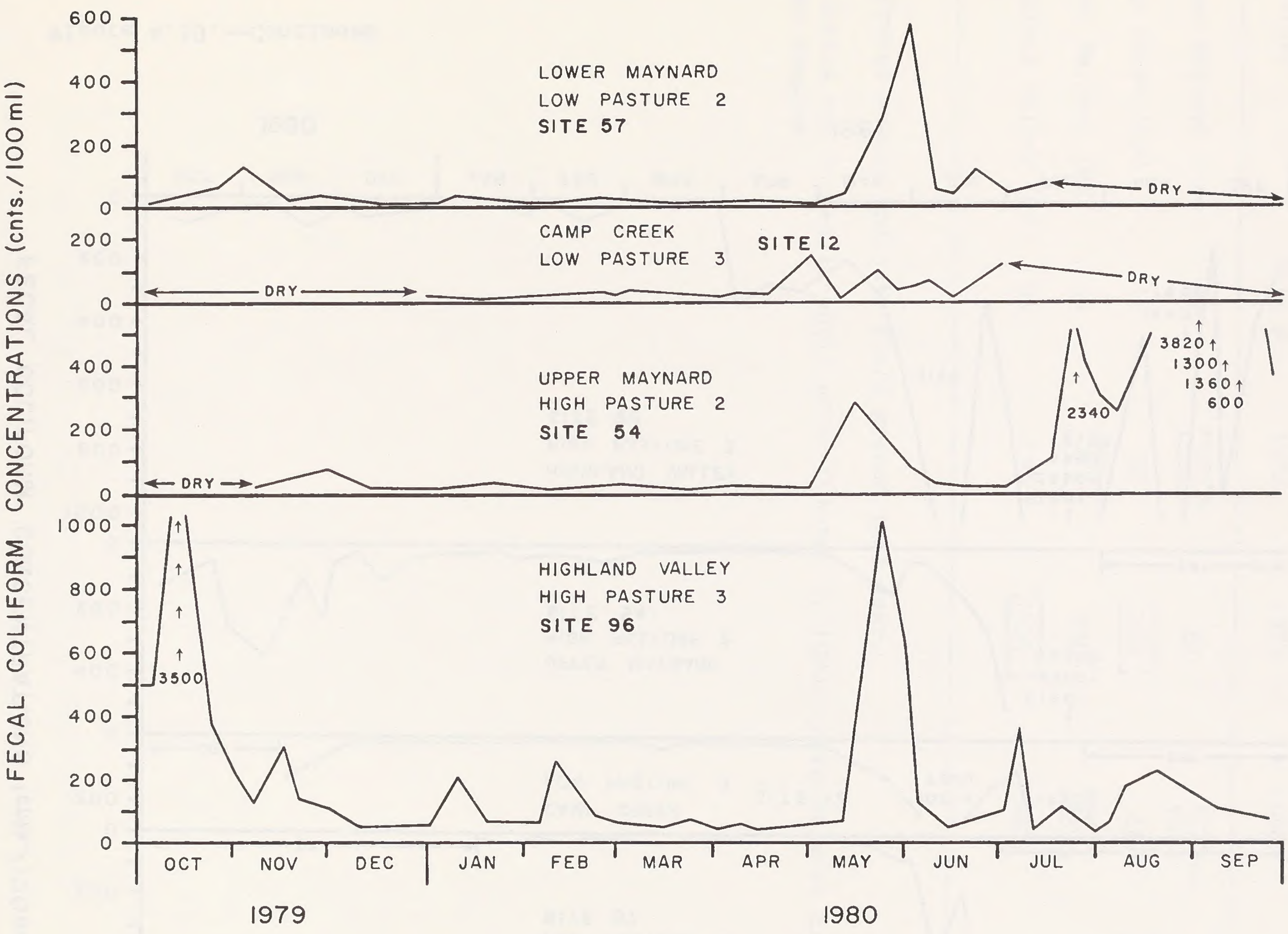


Figure 4.10.--Continued



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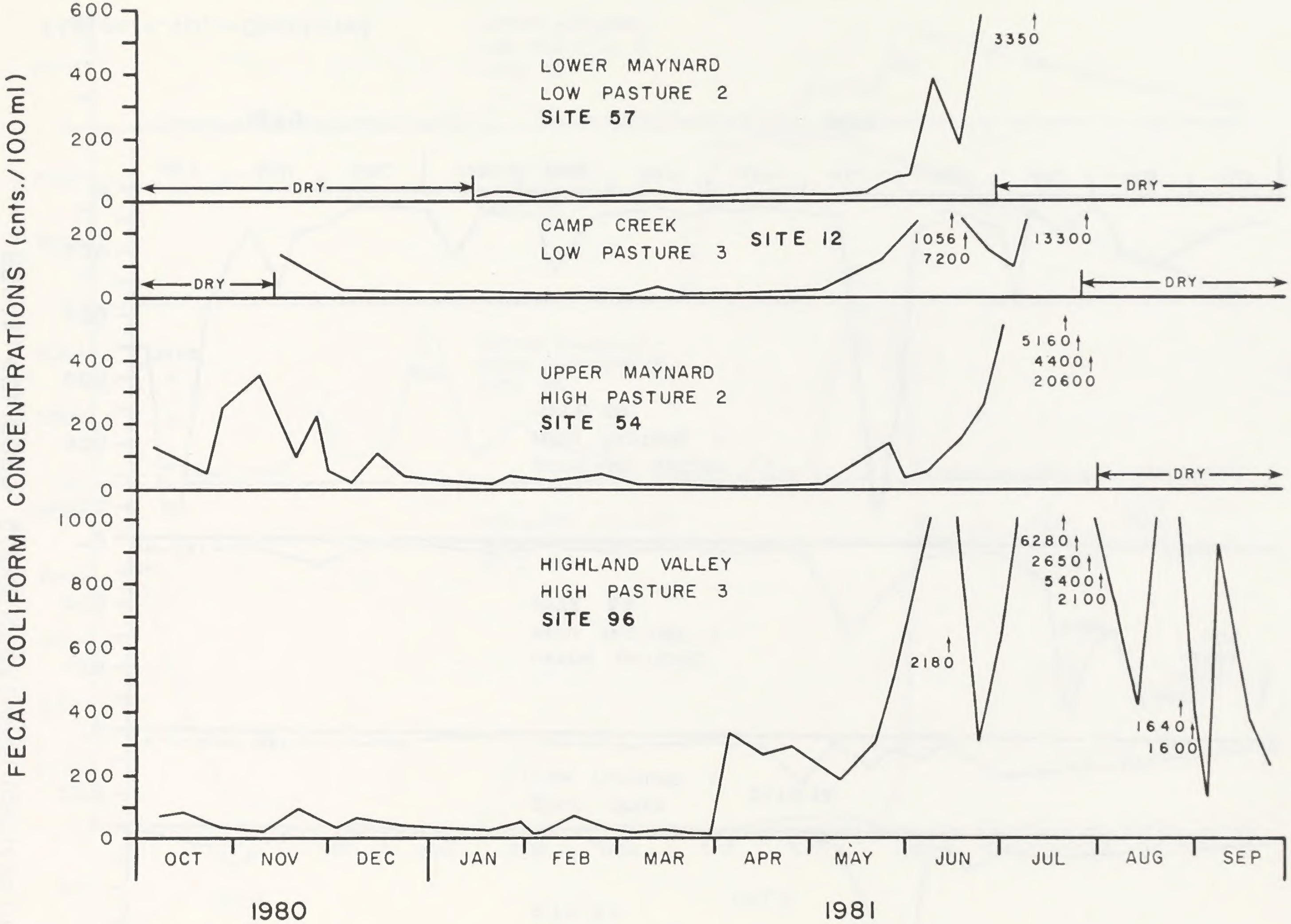


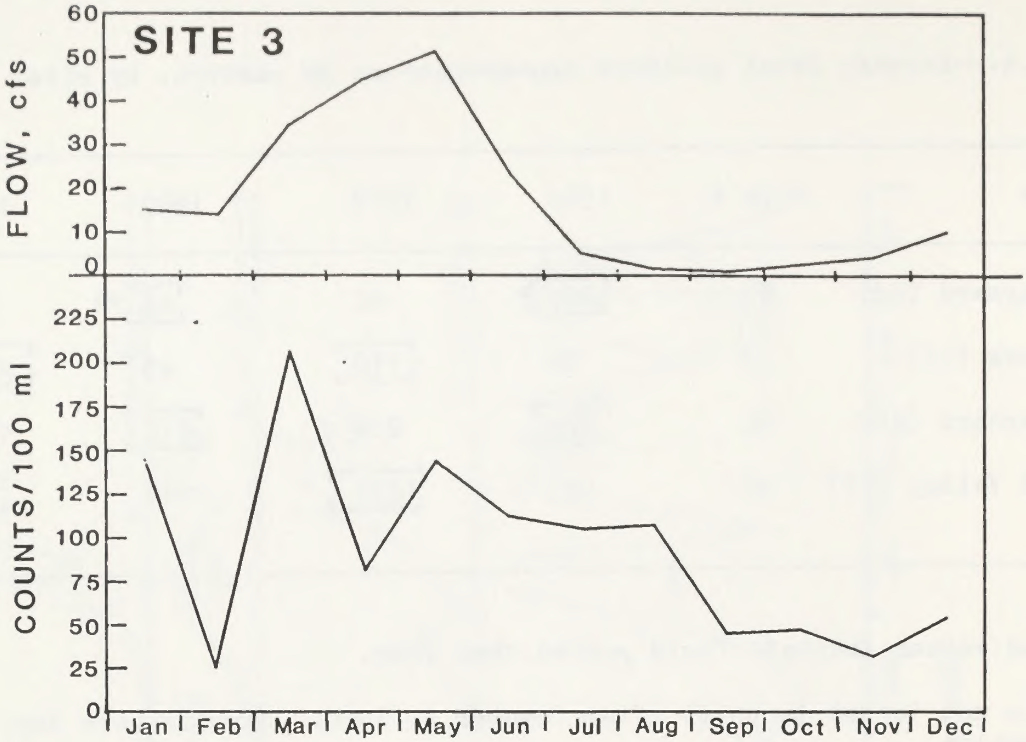
Figure 4.10.--Continued

Table 4.4.--Average fecal coliform concentrations by pasture, by site.

Pasture	Site #	1978	1979	1980	1981
Lower Maynard (L2)	57	$\boxed{225}$*	82	$\boxed{49}$**	252
Camp Creek (L3)	12	38	$\boxed{110}$	45	$\boxed{4062}$
Upper Maynard (H2)	54	$\boxed{217}$	230	$\boxed{310}$	1262
Highland Valley (H3)	96	193	$\boxed{1295}$	240	$\boxed{704}$

* Framed values indicate field grazed that year.

** Cattle not turned in until after October 1, 1980. Streams were dry; no samples.



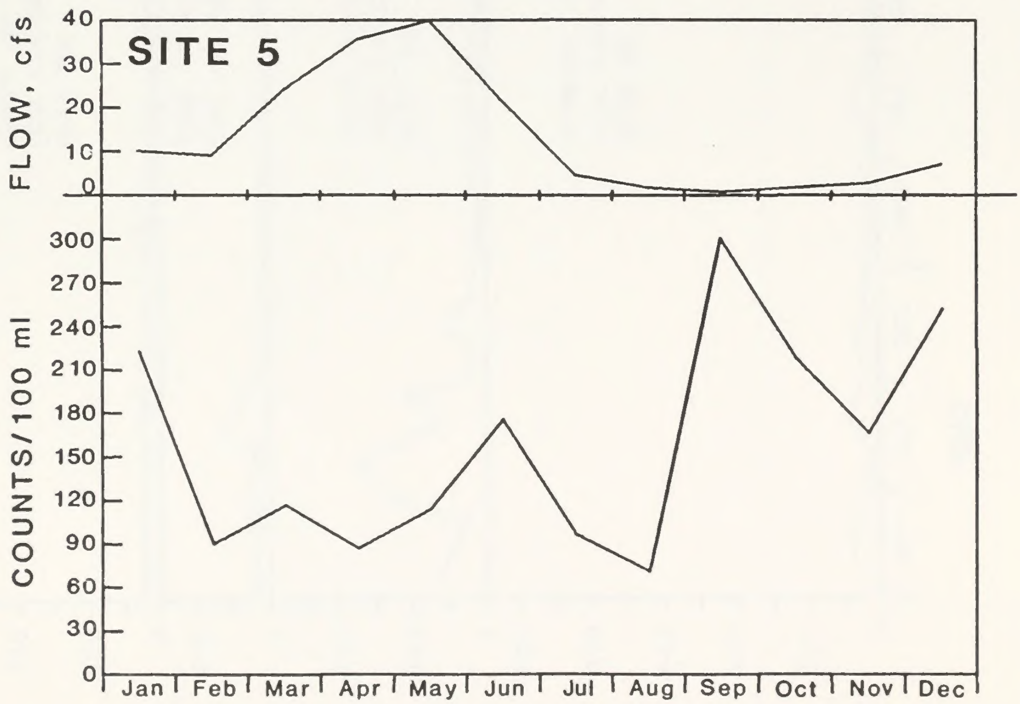


Figure 4.11.--Average monthly streamflow and fecal coliform concentration; 1972-1978.

located along the main channel of Reynolds Creek adjacent to irrigated pastures where cattle are fed from October through March of each year (Figure 4.1). Runoff from these pastures flows directly into Reynolds Creek. Approximately 2,000 cattle are fed in these winter pastures, with 100-500 cattle in 25-300 acre fields at any one time. These pastures are all subject to runoff from storm events and irrigation, which flush bacteria from the fields into the stream. Figure 4.11 shows that peak bacterial concentrations are more directly related to runoff events at these two sites than was the case at the sites on open range, Figure 4.8. Very little snow cover occurs at these two sites and the ground surface is frozen during most of the winter months, enhancing runoff and the flushing effect. The effect of irrigation return flow washing bacterial colonies off the soil into the stream is evident from April through August in some fields. A detailed analysis of runoff from one of these fields is given later.

The peak bacterial concentrations at sites 3 and 5 during early fall (Figure 4.11) reflect the return of cattle to these fields from open range. Bacterial concentrations remain high during the winter feeding season and are lowest during the summer, when cattle are moved to open range. Several operators feed calves and a few horses in these pastures during summer months, which accounts for increased bacterial concentrations at this time. This is especially noticeable in 1975.

A separate study was developed to determine loading effects of runoff from individual pastures before mixing with the streamflow. For this study, six pastures, approximately two acres each, were used (Figure 4.12). Two of the pastures were without cattle and used as a reference, two contained the normal distribution of cattle for winter feeding (four/acre), and two contained four times normal. The latter was to determine the impact of overcrowding on quality of runoff. Alfalfa-brome grass mixture, the most common hay mix used in this area, was the hay cover on the fields used for this study. During the course of the study no runoff was recorded from precipitation. All runoff and samples were taken from irrigation. Further details and indepth analyses can be found in Dixon et al. 1977, 1981.

Table 4.5 gives average concentrations for the most significant indicators from the study. These data were obtained from three irrigation events, each year, over a three-year period, 1979, 1980, 1981,--one in April, one in May, and one in June. The results show that the addition of cattle add significantly to the increased concentration of these selected indicators, especially from the four times normal field. As runoff from these pastures flows into Reynolds Creek, dilution occurs and most concentrations are reduced considerably downstream (note Figure 4.11, site 5, which is about 1 1/2 miles downstream). For most of the pastures, however, the irrigation water is dumped onto other fields downslope with much of the water returning to Reynolds Creek as subsurface flow, reducing pollution concentrations considerably.

Alternate Water Sources

One of the major objectives of the overall water quality cooperative program was to recommend and evaluate improved management practices. Water quality data collected over this period of study was reviewed for the purpose of recommending improved management practices. The major source of pollution along Reynolds Creek and satellite study areas is

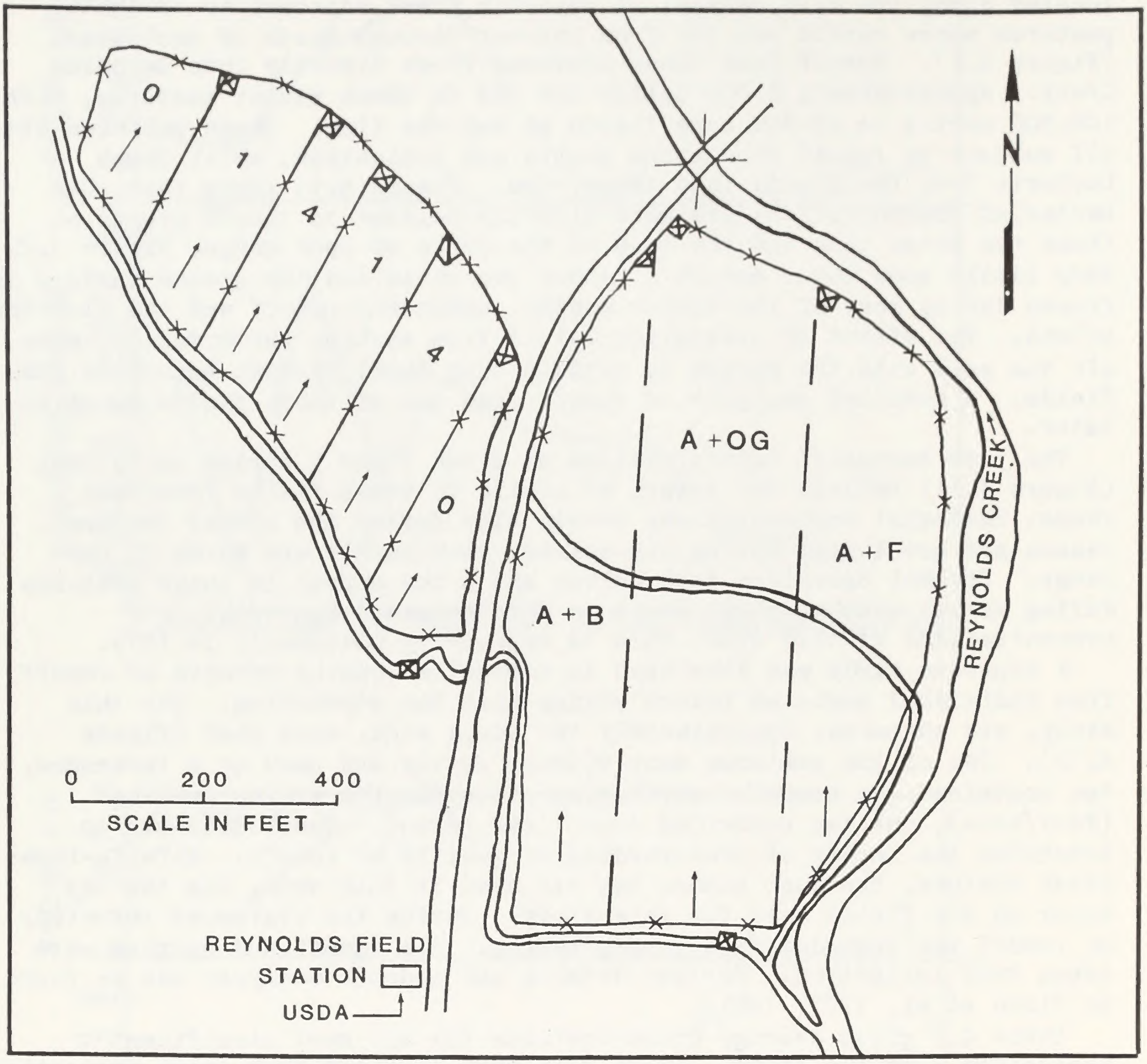


Figure 4.12.--Pasture study site.

Table 4.5.--Average values for selected indicators.

	NO CATTLE			NORMAL (4/A)			4 x NORMAL (16/A)		
	A	M	J	A	M	J	A	M	J
Ammonia	<0.1	<0.1	0.2	1.0	0.2	0.8	8.3	1.0	0.7
Nitrate-N	0.4	0.2	0.1	2.4	0.8	0.7	14.3	2.7	1.0
Organic-N	4.9	3.9	3.9	7.0	2.8	4.9	25.2	5.3	4.8
Total-P	2.9	1.8	1.2	4.9	2.3	2.5	14.2	4.1	2.9
Sodium	23.6	91.6	82.6	51.0	78.0	68.1	154.6	66.5	59.4
Potassium	7.7	22.4	27.6	30.1	26.5	21.7	115.2	44.2	37.2
Calcium	21.1	66.3	42.8	54.6	50.4	41.6	96.2	39.2	30.2
Magnesium	9.0	27.0	25.3	22.2	43.3	23.1	36.8	19.7	20.1
Chloride	7.6	16.1	3.7	43.2	18.2	1.0	97.8	39.2	5.6
C.O.D.	15.2	9.2	5.8	38.2	33.0	13.1	62.7	43.2	16.4
Fecal Coliform	88	40	2	3860	354	117	9150	1250	361

livestock, primarily cattle; and the major indicator of this source is microbiological--specifically fecal coliform bacteria. The following management practices are those considered the most practical and effective for improving downstream water quality from upstream grazing.

For livestock grazing on rangeland, greater emphasis should be given to:

1. Developing springs and shade upland, away from free-flowing streams;

2. Transporting water for livestock by pipeline or ditch from streams or wells to remote sites away from streams;

3. Salt and mineral blocks should be located in upland areas away from major streams; and

4. Livestock should not be concentrated in holding corrals adjacent to streams.

Collectively, these recommendations are pointed towards the reduction of cattle contact with the streams, by offering alternative sources of drinking water. It is realized that this is not possible in all situations, especially where terrain is steep and the riparian zones are the only sources of water, grass and shade.

In order to evaluate the recommendation of keeping cattle away from streams by offering alternative drinking water sources, a study was developed using BLM spring developments in the deferred rotation grazing unit on Reynolds Creek.

The study was made to verify the effect of spring developments in upland areas on reducing pollution in free-flowing streams. In the deferred grazing system in the northwest portion of Reynolds Creek (hatchered areas shown in Figure 4.1), approximately 1,000 head of cattle are grazed in fenced allotments each year for two to four-week periods. Water samples have been collected and analyzed for four years from stream sites within these allotments. In 1976, a spring development was constructed in the upper reaches of the Salmon Butte allotment.

The fecal coliform concentrations are given in Figure 4.9 and for the Salmon Butte and Soldier Cap allotments. Following construction of the spring, annual average fecal coliform concentration for the Salmon Butte allotment decreased, except for 1977. The 1976-77 winter drought storms and resulting runoff concentrated the fecal coliform bacteria in the water, giving the higher concentration in 1977. Data from the Soldier Cap allotment, Figure 4.9, are given for comparison, as the stream is the major source of stock water in this allotment.

Even though the general trend for fecal coliform concentration in the Salmon Butte allotment is down (except for 1977), a more quantitative expression can be made by looking at the ratio of counts for the Soldier Cap versus Salmon Butte allotments (Figure 4.13). From 1975 through 1978, the ratios increase from 1.33; 1.92; 2.04; and 3.89, respectively. Except for the spring development in the Salmon Butte allotment, all other factors remain equal through these four years. These results help verify the premise that these upland spring developments are a successful management tool for reducing sources of pollution in rangeland watersheds.

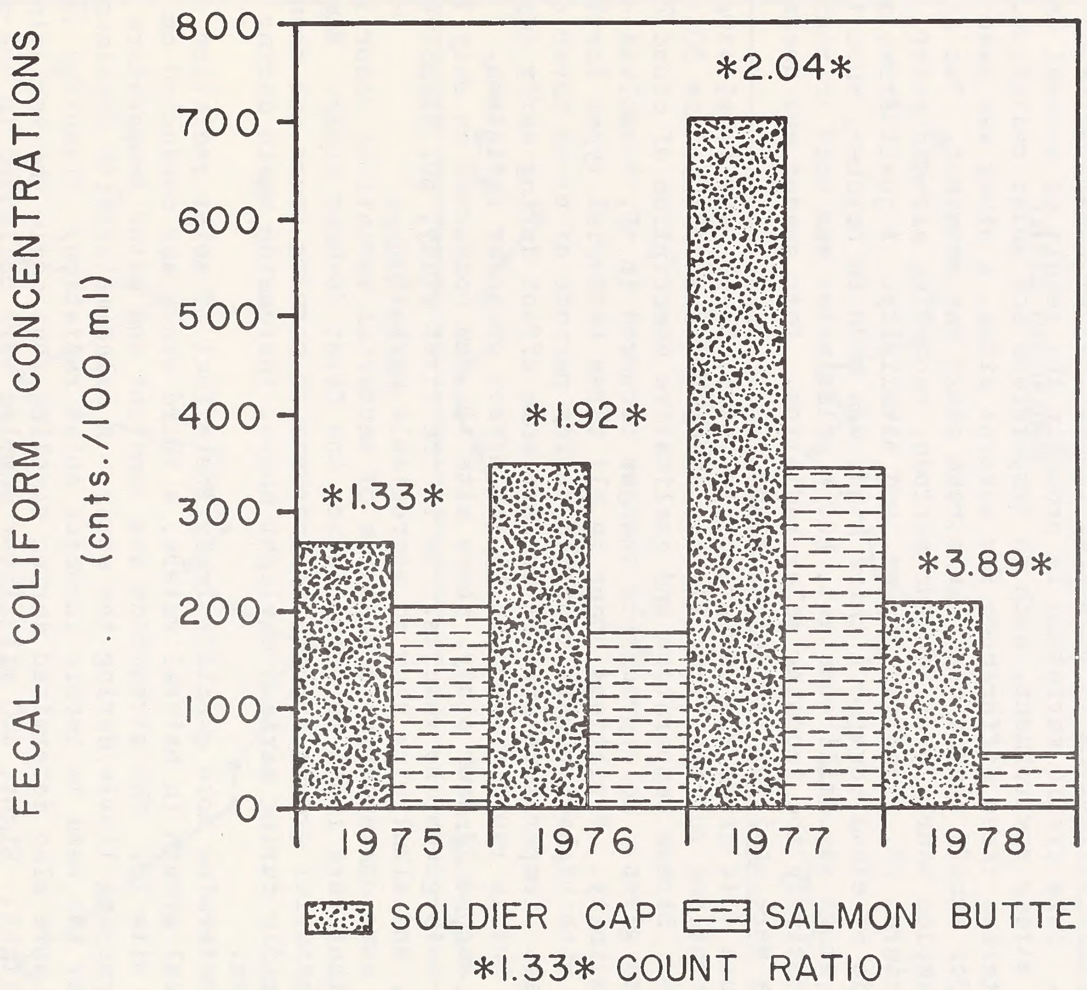


Figure 4.13.--Average annual fecal coliform concentrations for Soldier Cap and Salmon Butte allotments. Reynolds Creek Watershed, 1975-78.

A second study to develop alternative livestock water sources used groundwater as a source, pumping from a well and distributing the water to tanks by pipeline over a nine square-mile area. Further details are found in (Stephenson 1973).

EFFECTS OF SELECTIVE PHENOMENA ON SOURCE OF POLLUTANTS AND QUALITY OF STREAMFLOW

Diurnal Variations

During regular sampling and analysis procedures, it became apparent that cyclic variations in bacterial concentrations occur over a 12-24 hour period. This cyclic variation is probably the result of several factors of the stream environment, such as temperature and solar radiation. To characterize these differences for several sites, a study was made after the major runoff season when the stream stage was constant. Two sites were sampled hourly over 24-hour periods, recording air and water temperature, pH, dissolved oxygen, and alkalinity. A qualitative record was made of cloud cover. A third study was made in October, when the stream stage was still constant, but a solarimeter was used to monitor quantitatively the incoming solar radiation. Both shaded and unshaded samples were used for the latter study.

Figure 4.14 gives the variations in total, fecal, and fecal strep concentrations for the first 24-hour study below site 10, June 30 - July 1, 1975. Stream temperature and qualitative description of cloud cover are also given. No appreciable changes occurred in pH, dissolved oxygen, or alkalinity. Variations occur in all three bacterial types for this study, with highest counts recorded during periods of cloud cover or darkness. Temperature appears to have some effect during early daylight hours, but is rapidly overcome by the effect of solar radiation.

The second 24-hour study, above site 13, was conducted on July 17-18. Figure 4.15 gives the results. As in the first study, pH, dissolved oxygen, and alkalinity show no appreciable variation.

The same characteristic features of bacterial variations occur in this study that were found to occur during the first 24-hour study. Namely, that bacterial growth appears to increase in morning hours and then drop off rapidly during maximum daylight hours, increasing again during darkness.

To determine more quantitatively the effect of solar radiation on bacterial growth in natural waters, a third study was conducted on October 15, at site 18. The streamflow was constant and water temperature was cool, varying little during the study. A solarimeter with continuous recorder was used to record incoming solar radiation. Dissolved oxygen and pH were also determined during sampling, but again the variations were only slight. Eight, 400 milliliter samples were collected in the early morning and kept in a frame directly in the stream so that the temperatures would remain approximately the same (shaded) so that air could pass over them, and four samples were left unshaded. Samples for bacterial analyses were collected from each set of containers and from the stream each hour for analysis, and temperatures recorded. Results of this study, which was conducted during daylight hours only, are given in Figure 4.16. The differences between water temperature of the 400 ml containers and the flowing water in the stream never exceeded 1° C.

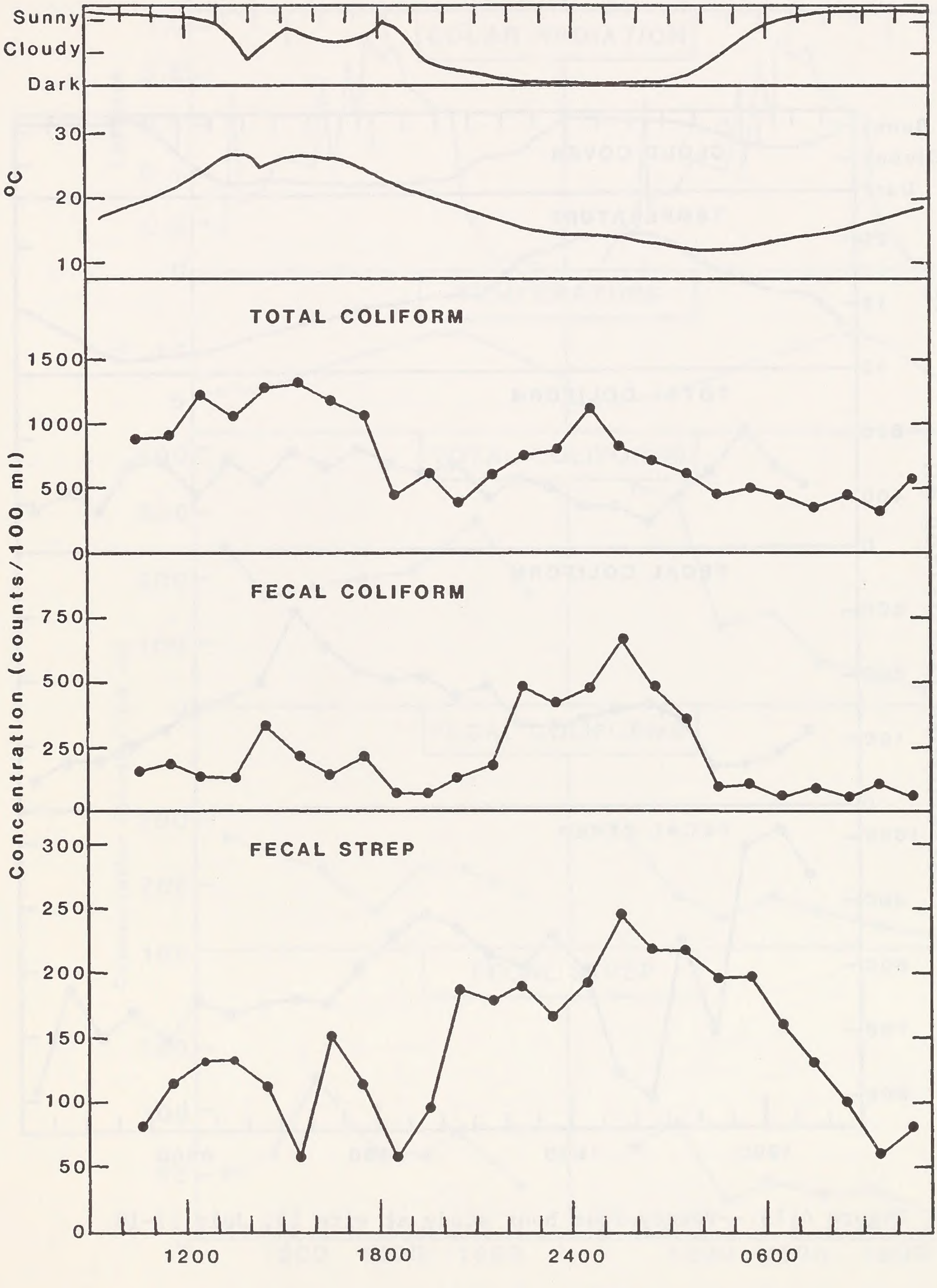


Figure 4.14.--Twenty-four hour study at site 10, June 30-July 1.

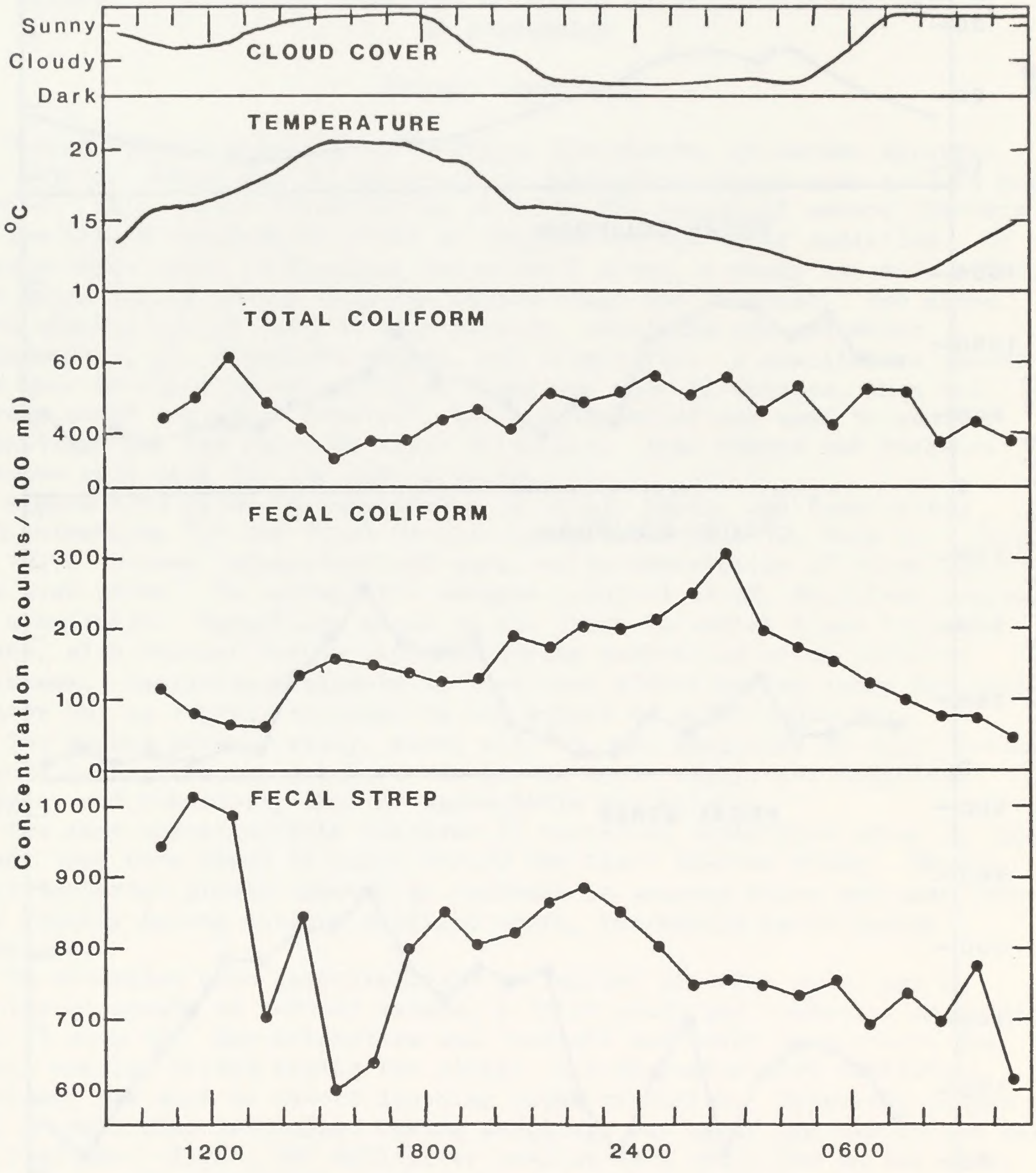


Figure 4.15.--Twenty-four hour study at site 13, July 17-18.

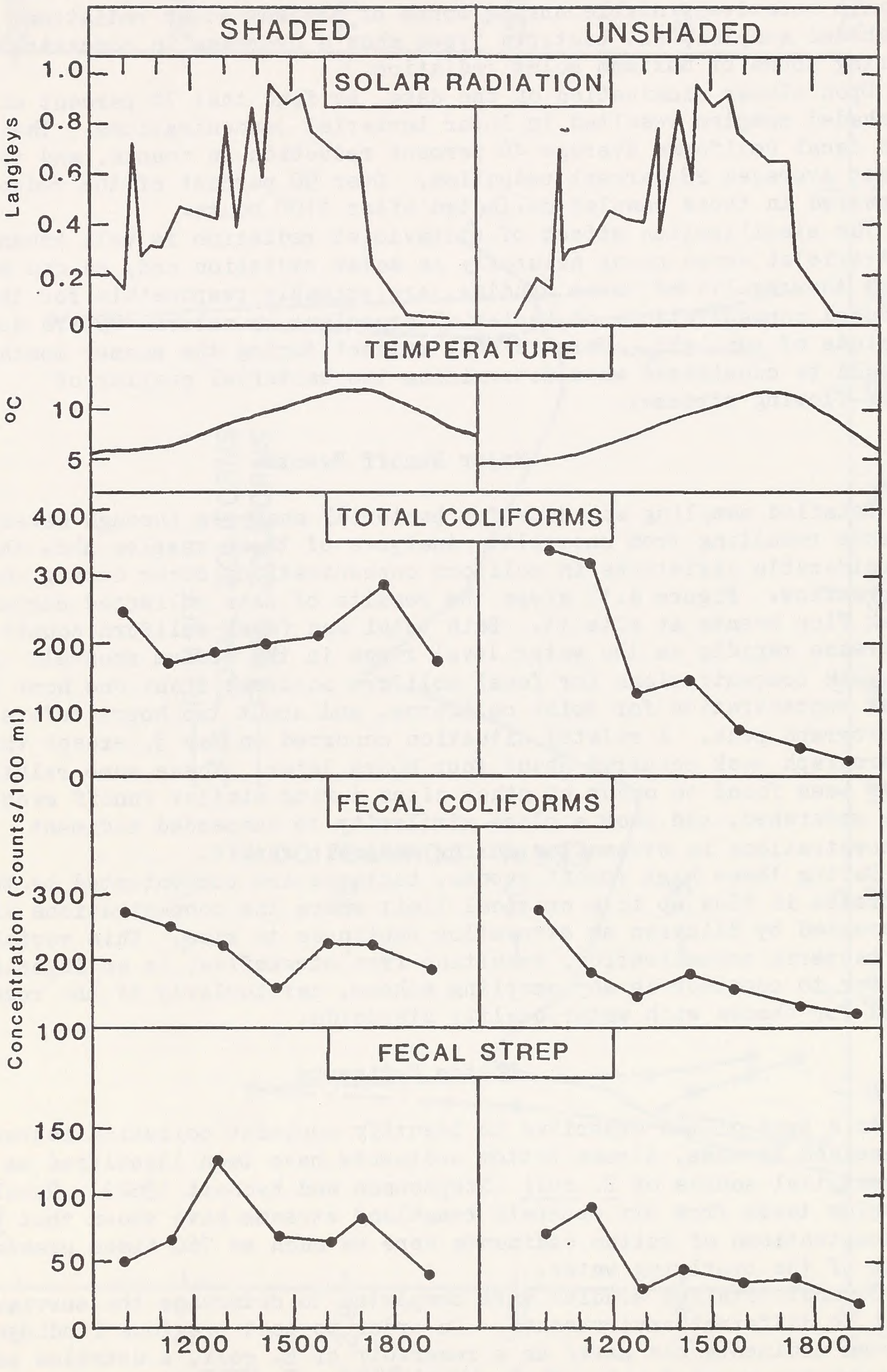


Figure 4.16.--Twenty-four hour study at site 18, October 15.

Bacterial growth for the shaded samples show a slight increase or remain relatively stable during hours of maximum solar radiation. For the unshaded samples, all bacteria types show a decrease in concentrations during hours of maximum solar radiation.

Upon closer examination of the data, we find that 70 percent of all the unshaded samples resulted in lower bacterial concentrations. The total and fecal coliforms average 40 percent reduction in counts, and the fecal strep averaged 28 percent reduction. Over 90 percent of the reduction occurred in those samples collected after 1100 hours.

The sterilization effect of ultraviolet radiation is well known. Ultraviolet waves occur naturally in solar radiation and, as can be seen from the results of these studies, are probably responsible for the reduced concentrations of bacterial organisms in natural waters during periods of sunlight. This is most evident during the summer months and should be considered when determining the bacterial quality of free-flowing streams.

Major Runoff Events

Detailed sampling was done for bacterial analyses through several flood events resulting from snowmelt. Analyses of these samples show that considerable variations in coliform concentrations occur during changes in streamflow. Figure 4.17 gives the results of data collected during two peak flow events at site 15. Both total and fecal coliform counts increase rapidly as the water level rises in the stream channel. On May 1, peak concentrations for fecal coliform occurred about one hour before peak concentration for total coliforms, and about two hours before the hydrograph peak. A related situation occurred on May 3, except that the hydrograph peak occurred about four hours later. These same relationships have been found to occur at other sites during similar runoff events on the watershed, and show a close similarity to suspended sediment concentrations in streamflow during snowmelt runoff.

During these high runoff events, bacteria are concentrated by the increase in flow up to a critical limit where the concentrations are then decreased by dilution as streamflow continues to rise. This variability in bacteria concentration, resulting from streamflow, is an important factor to consider in any sampling scheme, particularly if the results are used for checks with water quality standards.

Bottom Sediments

As a part of the objective to identify nonpoint pollution sources on rangeland streams, stream bottom sediments have been identified as a substantial source of *E. coli* (Stephenson and Rychert 1982). Results from samples taken from six separate rangeland streams have shown that *E. coli* concentrations of bottom sediments were as much as 760 times greater than that of the overlying water.

Several detailed studies were completed to determine the survival of *E. coli* in different environments. In order to test previous findings, that stream sediments can serve as a reservoir of *E. coli*, a detailed sampling network was carried out. The mean *E. coli* concentrations for the sediment to water ratio was 13.5, confirming previous findings. *E. coli* survival in the stream sediments is often carried over from one grazing season to another, and frequently experiences regrowth. *E. coli* in the overlying

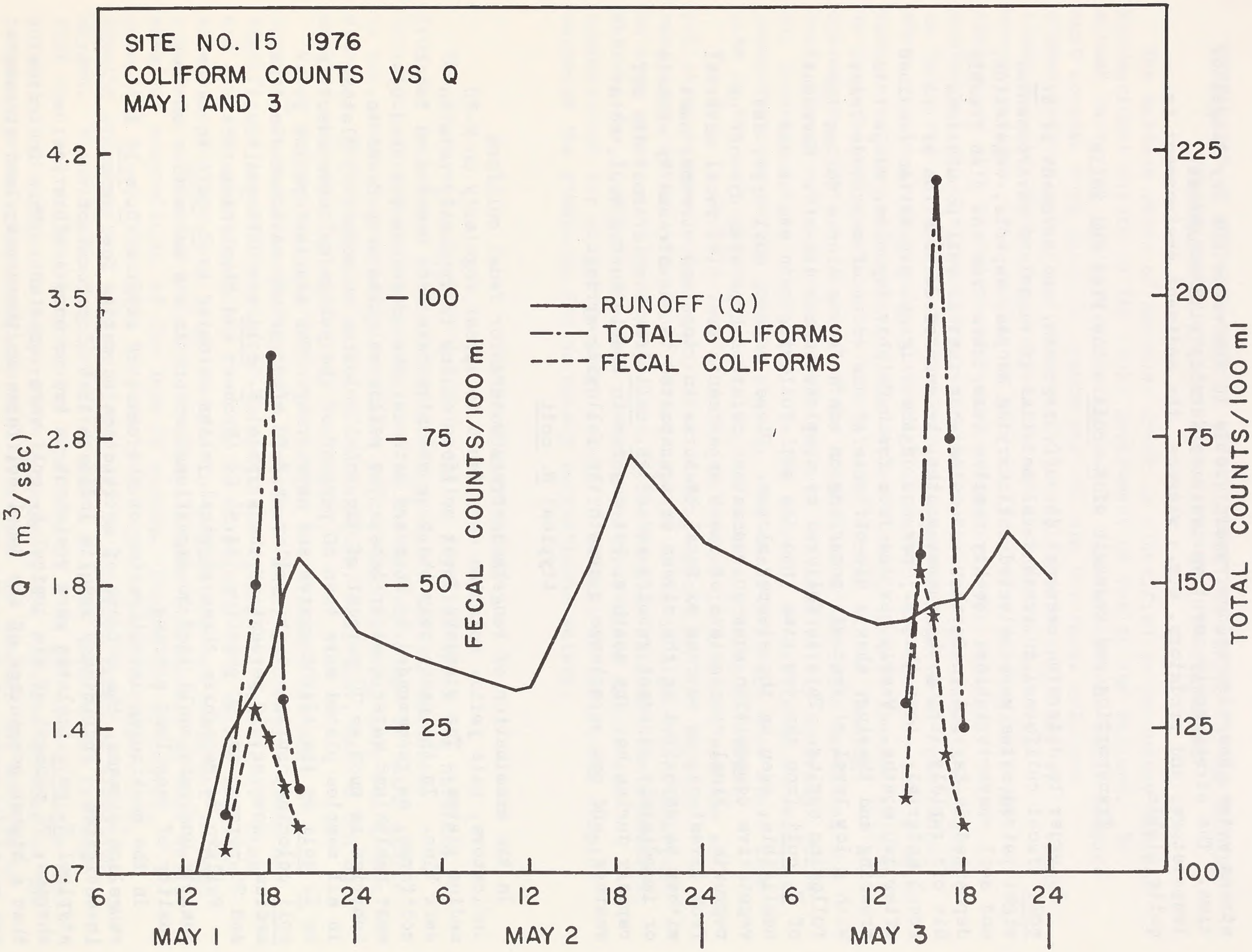


Figure 4.17.--Variation in bacterial concentration with runoff during snowmelt runoff.

stream water, however, seldom remain viable in the water for any length of time. The stream environment varies considerably with roughness, temperature, and predators, etc.; whereas, the sediment environment is quite stable.

Transporting and Regrowth of E. coli - Cow Pies and Soils

In order to determine seasonal die-off, regrowth, and movement of *E. coli* (fecal coliforms) in fresh fecal material in rangeland environments, eight paired sites were selected with varying slopes, aspects, vegetation, and soil characteristics. Weekly samples were taken from cow pies freshly deposited in May and in October. Results show that *E. coli* populations die off rapidly during the summer months, because of desiccation of the fecal material. Less than 0.1 percent of the original population remained after two months. Weekly samples from fresh October deposits, subject to freezing and thawing, show a die-off rate of one order of magnitude less, with a low level of regrowth occurring on south facing slopes during the following spring. This is followed by complete summer die-off. Movement of *E. coli* from the cow pies into the soil following rain storms was negligible, even on the steeper slopes. Slope, aspect, soil type, and vegetative composition show no consistent relationships with die-off or regrowth. Final conclusions of these experiments are: (1) fecal material from livestock, as sources of fecal bacteria in rangeland streams, must either be deposited in the stream or transported to the streams by animals or immediately adjacent runoff; and (2) *E. coli* (fecal coliforms) die off rapidly during hot dry weather, but may remain viable during cool, moist weather, and can experience regrowth the following spring.

Atypical E. coli

In the examination of rangeland stream waters for fecal coliform indicators, pale yellow colonies were found to appear regularly on M-FC medium plates. The standard fecal coliform colony is typically pale to dark blue. In the past, only the blue colonies have been counted as fecal coliforms, as recommended by Standard Methods, the procedure was used by most health and water quality labs. The yellow colonies were found to comprise as much as 70 percent of the total colonies on some M-FC plates. In all samples plated more than 80 percent of the yellow colonies identify as *E. coli* by the AP120E system and serotyping. The atypical yellow *E. coli* colonies continue to be yellow on M-FC after growth in a nonselective medium. However, 50 percent of the atypical *E. coli* are ONPG-positive, and 20 percent are EC positive (44.5° C) (Rychert and Stephenson 1981).

Failure to recognize these atypical yellow colonies as *E. coli* in water quality analysis could lead to significant errors in the estimation of the quality of rangeland streams.

In the continuing investigation of the cause of atypical *E. coli* in rangeland streams, the effects of antibiotics in cattle feed were investigated. Preliminary results indicate that 13 percent of the atypical *E. coli* isolates were resistant to two or more antibiotics; whereas, 72 percent of the typical *E. coli* were resistant. This indicates that a higher percentage of the fecal coliforms in these rangeland streams are multiply-resistant to antibiotics, and could represent a significant health hazard not previously recognized (Rychert and Stephenson, submitted for publication).

COMPARISON OF NONPOINT SOURCES OF POLLUTION FOR WINTER CATTLE FEEDING VERSUS SUMMER GRAZING WITH WATER QUALITY STANDARDS

The surface water of Reynolds Creek is classified as Secondary Contact Recreational waters by the Idaho Department of Health and Welfare. To exceed bacterial quality standards in this classification, water samples must contain more than 800 counts per 100 mls for fecal coliform concentrations. Over a 4-year period, samples were collected at 11 sites along Reynolds Creek and analyzed for fecal coliform bacteria concentrations. The results of this analysis were put together for comparison with Idaho's water quality standards for bacteria concentrations for secondary recreational waters. The results are given in Table 4.6 and show that those stream segments located on open range, where cattle graze from April through September, are far less likely to be nonpoint sources of pollution than those stream segments located adjacent to pastures where cattle are concentrated during winter feeding operations. Site 1, located at the confluence of Reynolds Creek and the Snake River, reflects year around pasture use immediately upstream. Site 22, located on open range, reflects the presence of cattle in above normal concentrations during grazing season. The small drainage area above this site is the main source of water for the entire grazing allotment.

The data in Table 4.6 reflect the difference in nonpoint sources of pollution between summer and winter feeding operations for typical rangeland cattle operations. There appears to be no significant problem on open range, as 5 percent or less of the samples exceeded the standards; whereas for locations adjacent or below pastures where cattle are concentrated for winter feeding, nearly 20 percent of the stream samples exceeded the standards for secondary recreational waters.

WATER QUALITY MODEL

The basic water quality model tested on Reynolds Creek was obtained from the Department of Civil Engineering, Water and Air Resources Division, University of Washington. It has the advantage of being simple to use, needs only readily available inputs, and requires only 162 K core storage. The model is a series of subroutines; and, thus, can be run on a smaller computer, using overlay techniques.

Water temperature and dissolved oxygen are probably the most significant variables in any body of water. Water temperature alone has a significant impact on rates of chemical and biological reactions. Fish and other aquatic organisms are able to adapt only to a narrow range of water temperature, and large changes in temperature can be lethal to many organisms. The result would be a change in the biological, as well as the chemical composition, of the lake or stream. Oxygen is, of course, essential to aquatic life; and, as in the case of water temperature, aquatic organisms are able to adapt only to a narrow range of dissolved oxygen. For example, 5 mg per liter are a minimum requirement for most fish species, while trout require a minimum of 7 mg per liter. Since the solubility of oxygen is temperature dependent, the combined effects of the temperature and oxygen regimes will determine the numbers and species of aquatic organisms present in a stream or lake. In other words, a change in the water temperature regime will result in a change in the oxygen regime. This will, in turn, affect the number and species of aquatic

Table 4.6.--Comparison of percent times bacterial water quality standards exceeded on rangeland sites versus pasture sites.

Site No.	Number of Samples	Max. Cnts.	Min. Cnts.	No. Times Standard Exceeded	% Times Standard Exceeded	Range (+) Pasture(-)
1	61	4550	0	12	19.7	(-)
2	49	750	0	0	0	(+)
3	107	864	0	2	1.9	(+)
5	107	400	0	7	6.5	(-)
14	80	1220	0	6	7.5	(-)
15	101	1680	0	8	7.9	(-)
16	86	560	0	0	0	(+)
17	98	700	0	0	0	(+)
18	90	524	0	0	0	(+)
21	95	1160	0	1	1.1	(+)
22	80	3000	0	4	5.0	(+)

organisms present. The situation can occur from releases of warmer water from irrigation return flow from agricultural sources, which may be high in BOD and low in dissolved oxygen. These changes are typical of most rivers and streams in the semiarid portions of the Northwest, where demands for irrigation water continue to increase. Irrigation, through return flow, increases water temperature and reduces the dissolved oxygen content. In this connection, diversion dams can greatly increase the water surface area, and, thereby, contribute to an increase in water temperature. Outfalls from feed lots and fields along the stream tend to be low in dissolved oxygen, high in BOD, and high in water temperature. Overgrazing of the riparian zone can also be detrimental to stream quality by increasing temperature and decreasing dissolved oxygen.

Since temperature and oxygen changes will most likely result in biotic and chemical changes, it is essential to be able to estimate the changes in the thermal and oxygen regimes resulting from the introduction of water, which is warmer, higher in BOD, and lower in dissolved oxygen into the natural system. It would also be important to estimate temperature and oxygen changes due to changes in the flow regime and a combination of flow changes and advective changes. This can be attempted by using a dissolved oxygen-temperature model. Changes predicted by the model can be compared with tolerance limits of the affected organisms. In this way, the concentration and volume of additional heat, BOD, and low oxygen water, which can be introduced without detriment, can be estimated. The model used should predict temperature to $\pm$ 2° F and dissolved oxygen to $\pm$ 1 mg per liter. No attempt was made to extrapolate data from outside Reynolds Creek to test the model on an ungaged stream.

Data Cost and Availability

Data cost and availability for the temperature portion of the model are small for the meteorological variables of air temperature, cloud cover, barometric pressure, relative humidity, and wind speed, since these are available from National Weather Service publications, although these are not near the water bodies in many cases. Discharges are often available from USGS publications, and solar altitude can be obtained from tabled values or charts. Stream geometry can be obtained from elevational river profiles, travel times, and discharges. Elevational profiles and travel times can represent a considerable expense in terms of manpower. Collection of actual values of water temperature and dissolved oxygen and biomass to calibrate the model are probably the most expensive item.

Procedure

The stream must be divided into reaches and flows must be estimated for each reach. Diversions and returns, in addition to natural inflows, must be estimated. Surface area of the reach can be calculated. Meteorological variables required can be obtained from National Weather Service publications.

Required Data Inputs

A. Title card

B. Initial conditions card

1. Water temperature - °F
2. O_2 deficit - mg/l
3. BOD - mg/l
4. Flow - cfs
5. Number of reaches +1
6. Starting time
7. Output switch
8. Input switch

C. Reach

Information for reach (seven cards for each reach), K_1^{20}, K_2^{20}, BOD added, added deficit, temperature of incoming water (°F), added flow, time to traverse reach (days), number of intervals

D. Next six cards
Net short-wave radiation (calculated from altitude of sun, percent cloud cover)
Atmospheric radiation factor B
Air temperature °F
Wind speed (knots)
Ambient vapor pressure (inches Hg)
Surface area of plus (acres)

Model Calibration

The model was calibrated to a data set collected on August 9, 1978, for three stream reaches. Travel time of the water was measured by using a float. Air temperature, relative humidity, water temperature, dissolved oxygen, BOD, percent cloud cover, stream width and depth, and wind speed were measured or estimated at sites 18, 17, and 16 (Figure 4.1).

For each reach, net short-wave radiation from percent cloud cover and solar altitude were calculated. The atmospheric radiation factor was calculated from ambient vapor pressure and percent cloud cover. Air temperature and ambient vapor pressure were measured at each station, and wind speed was estimated for each reach.

The model was first made to match the observed water temperatures at each station by varying the net short-wave radiation and wind speed inputs. Net short-wave radiation was decreased from the calculated values for each reach. This is because of shading of the water surface by vegetation and steep canyon walls, resulting in less short-wave input than that calculated from solar altitude and cloud cover. This is presently a serious defect of the temperature portion of the model, and will require the development of a shading factor to be applied to the calculated net short-wave radiation.

After satisfactory water temperature agreement was obtained, BOD calibration was attempted by varying K_d^{20}, the de-oxygenation coefficient, in small steps until satisfactory BOD agreement was obtained for each station.

Next, dissolved oxygen content was matched to observed values by varying K_2^{20}, the re-oxygenation coefficient, in steps until satisfactory dissolved oxygen agreement was obtained for each station.

The results of this calibration procedure are listed in Table 4.7. Excellent agreement was obtained for all variables, but the values of the coefficients K_d^{20} and K_2^{20} are much lower than those reported in the literature.

This may be due to the fact that the reported values of these coefficients were developed on much larger streams having much greater surface areas, depth, and discharges.

Figures 4.18 and 4.19 indicate the sensitivity of K^{20} at the actual water temperature and BOD for each reach. Figure 4.18 indicates that for reach 2, K_2^{20} can vary from 0.25 to 4.40, and still simulate dissolved oxygen content to $\pm$ 1 mg/l. Figure 4.19 indicates that for reach 3, K_2^{20} can vary from 0.20 to 2.00, and simulate dissolved oxygen content to $\pm$ 1 mg/l.

It would appear, at the present time, that the model can produce an acceptable simulation of water temperature, dissolved oxygen, and BOD. Because of simple model construction, it should be possible to add other water-quality variables in the future with a minimum effort.

COMPARISON OF GRAZING PRACTICES

An effort has been made to develop a method by which the effects of grazing practices on water quality can be compared. The method used for this preliminary work is given in Figure 4.20. Fecal coliform data from four different grazing practices were used, plotting the concentration on log-probability paper. Characteristics of the different practices are given in Table 4.8. Data collected and reported in past years on the Reynolds Creek Watershed were used in this analysis, along with the Boise Front data.

The value of this method of comparison could best be used for determining which system is most likely to produce fecal coliform concentrations in exceedance of any particular level. For example, water quality standards for the streams sampled are 800 counts of fecal coliform bacteria as the upper limit. The percent chance of exceeding this limit for the sites in the different grazing systems used here are given in Table 4.9. A subunit of the open system, a 100-acre watershed that contains a perennial stream, was included. Cattle favor this area of the open system because of easy access, plush grass, good water, and shade. Because of these characteristics, frequency of contact to the stream is greater and the fecal coliform concentrations are higher.

Because of the different grazing intensities of the systems and the different physical characteristics within each area, more vigorous use of this method is not justified without additional data. However, it can be used on an annual or long-term basis to compare these particular systems in their present use. Any gross changes in AUM, vegetative cover, etc., would make further evaluation necessary.

Figure 4.21 gives the geometric mean of fecal coliform counts at 11 sites along the main channel of Reynolds Creek over the period of record, 1972-1978. The location of these sites is found in Figure 4.1, and the site description on Table 4.1. Sites 1, 5, 14, and 15 are located on channel segments, which are adjacent to pastures where cattle are fed during winter months; or, as in the case of Site 1, the entire year. At all four of these sites, cattle have free access to the stream for drinking water. Site 3, although located on rangeland, is only a short

Table 4.7.--Results of model calibration for water temperature, dissolved oxygen, and BOD.

STATION	OBS.	SIM.	OBS.	SIM.	OBS.	SIM.		
18	59.0	---	7.50	---	7.00	---	----	----
17	64.4	64.4	7.25	7.27	7.25	6.99	0.004	1.80
16	77.9	77.9	6.00	6.00	5.75	5.76	0.193	0.67

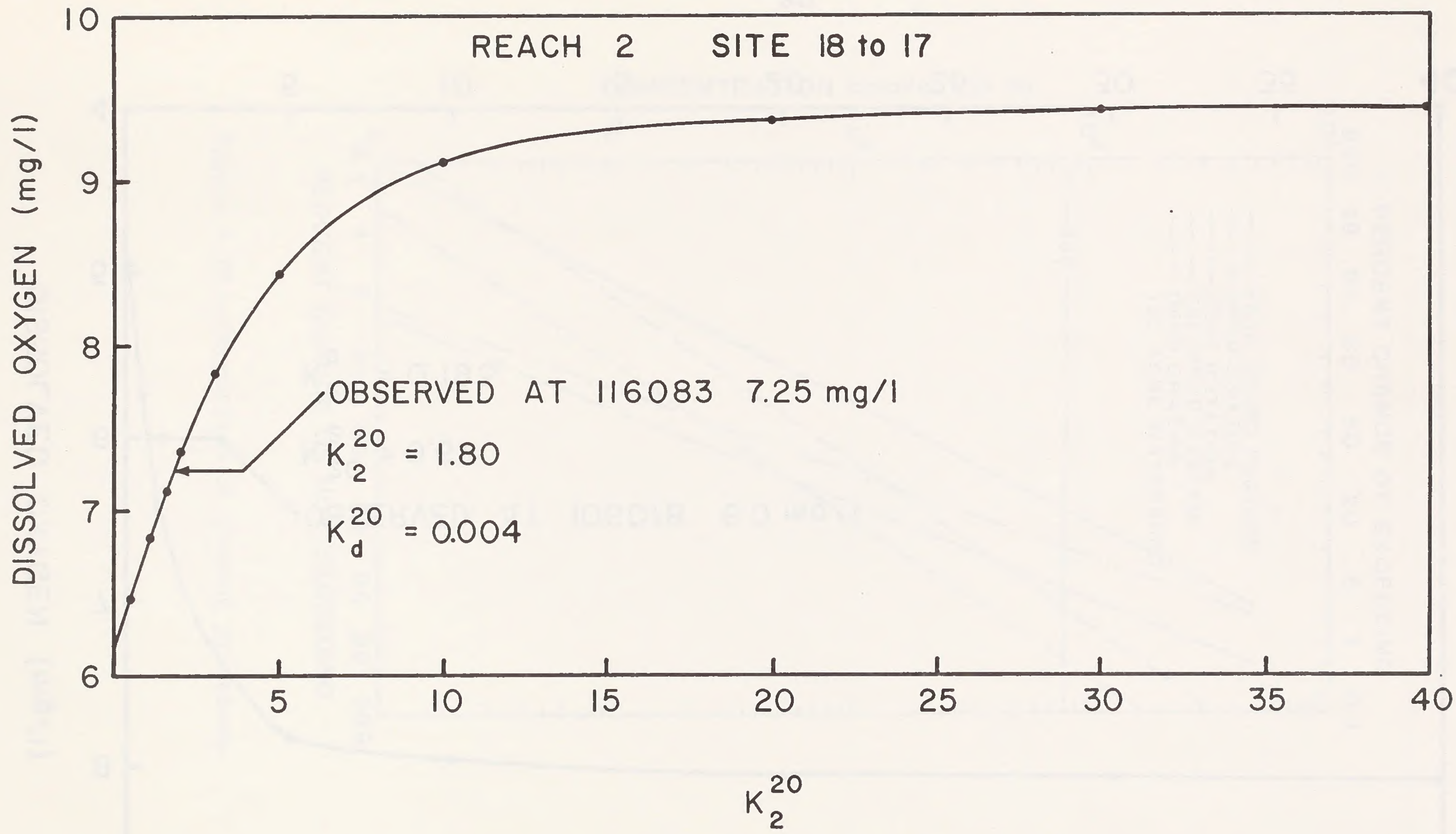


Figure 4.18.--Variation of dissolved oxygen with re-oxygenation coefficient for reach 2 (Fig. 4.1.).

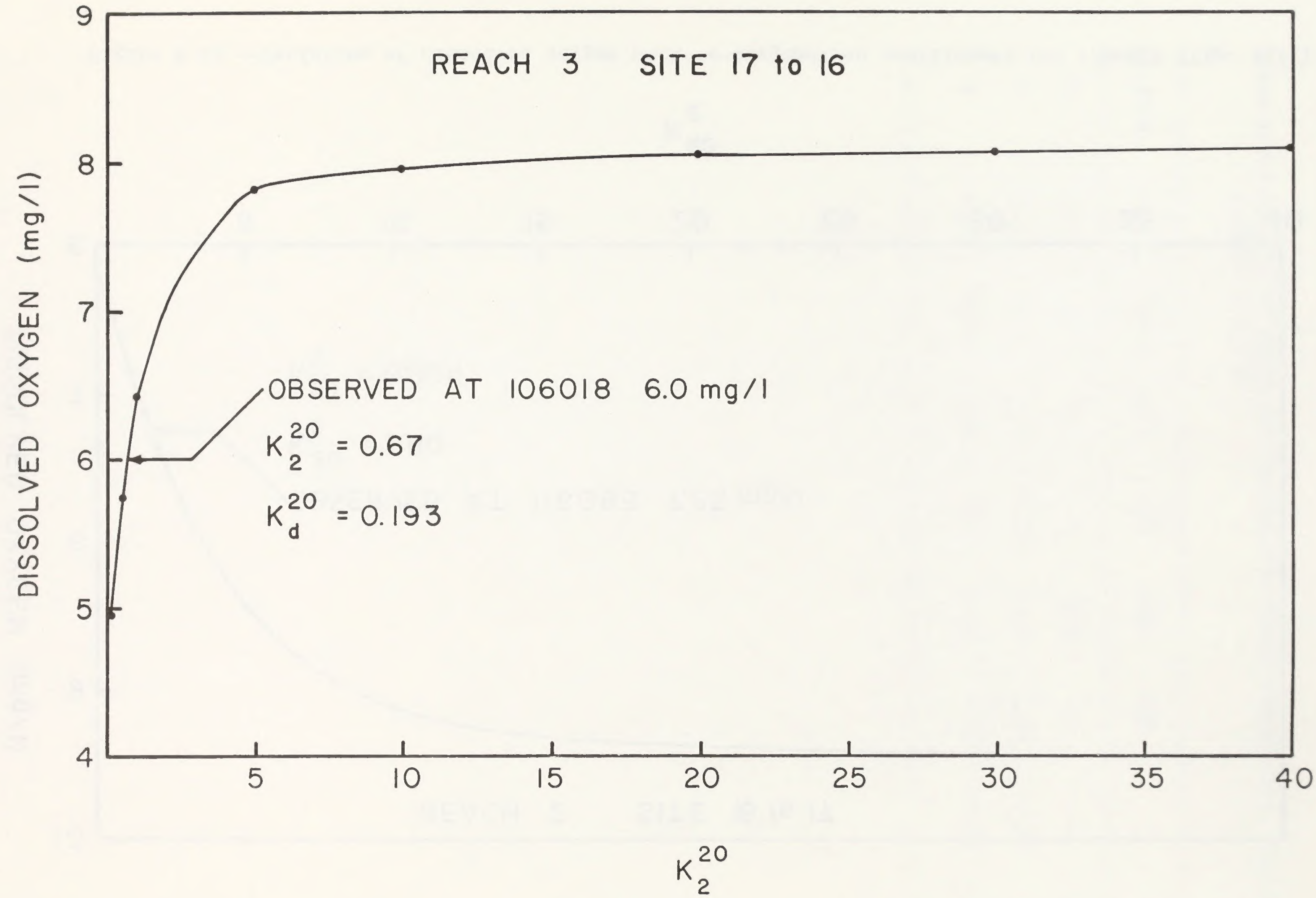


Figure 4.19.--Variation of dissolved oxygen with re-oxygenation coefficient for research 3 (Fig. 4.1.).

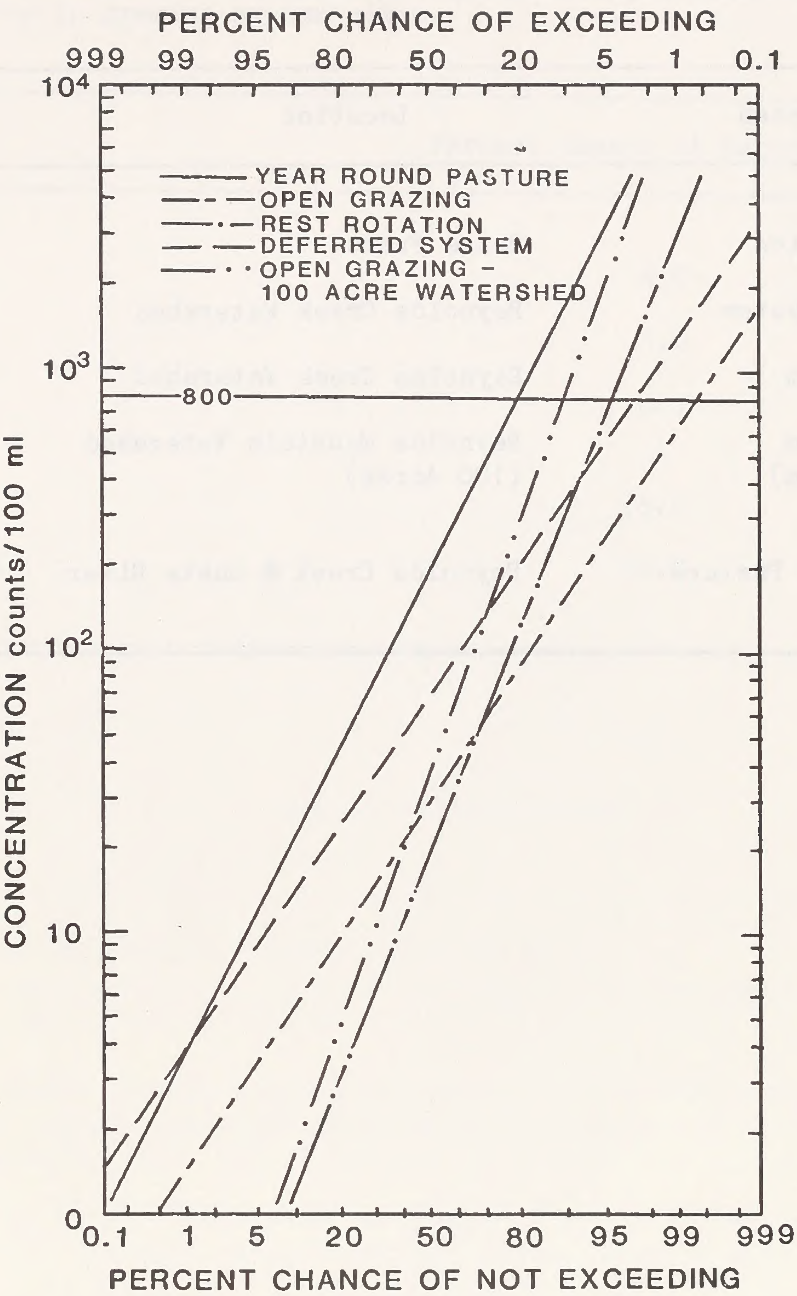


Figure 4.20.--Comparison of grazing practices.

Table 4.8.--Grazing practice characteristics.

Grazing System	Location	Ac/AUM
Rest-Rotation	Boise Front	5
Deferred System	Reynolds Creek Watershed	6
Open System	Reynolds Creek Watershed	18
Open System (Sub-System)	Reynolds Mountain Watershed (100 Acres)	18
Year Round Pasture	Reynolds Creek @ Snake River	5 cows/acre

Table 4.9.--Percent chance of exceeding 800 counts of fecal coliform bacteria in grazing system sites.

Grazing System	Percent Chance of Exceedance
Rest-Rotation	4.0
Deferred System	3.0
Open System	0.7
Open System (Sub-System)	15.0
Year Round Pasture	20.0

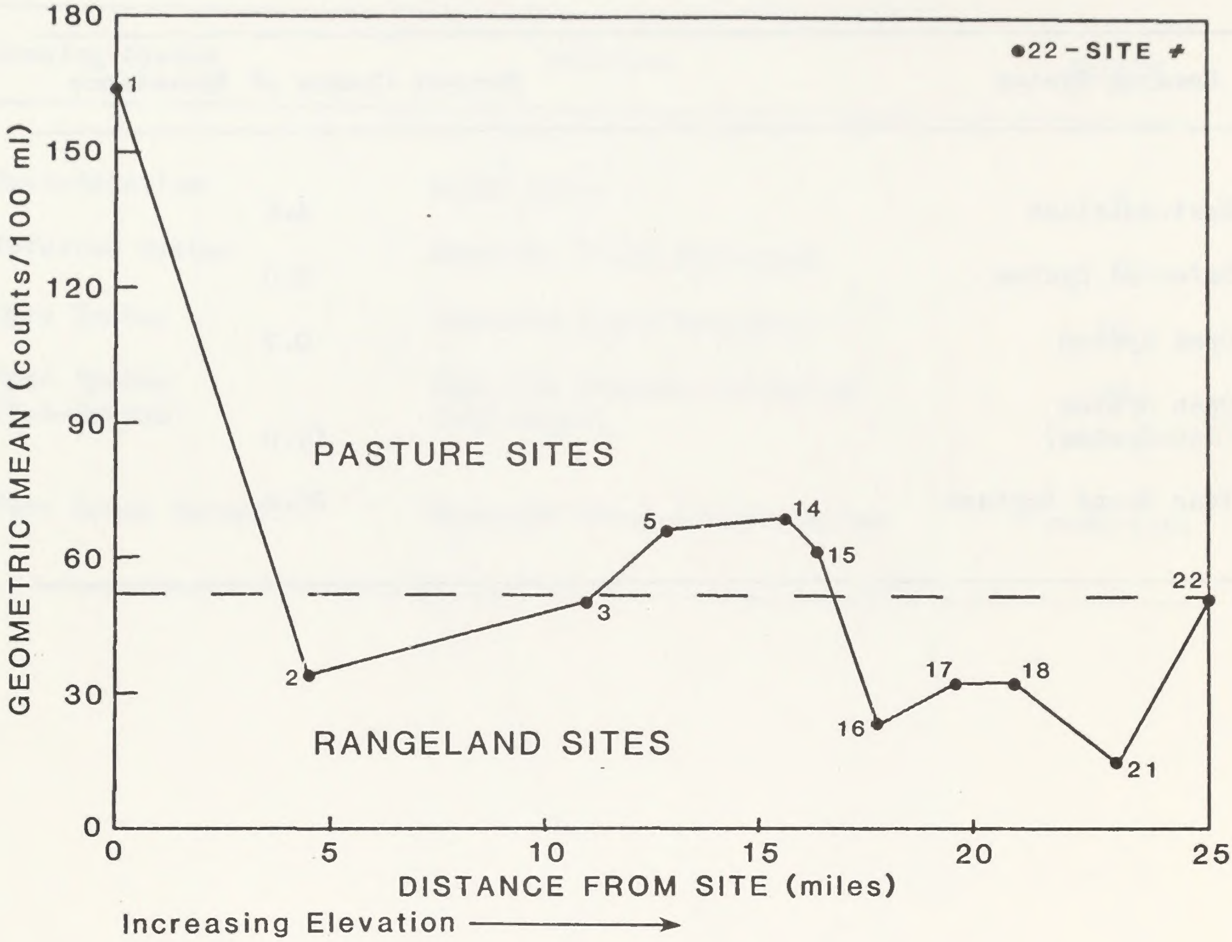


Figure 4.21.--Geometric mean of fecal coliform concentrations at sampling sites along Reynolds Creek.

distance downstream from a pasture and is influenced by pasture runoff. Site 22 is located at the headwaters of Reynolds Creek in a small area of open range, where cattle concentrate for drinking water.

As seen in Figure 4.21, most sites where elevated counts occur, the concentrations are reduced rapidly downstream. This is particularly true along stretches of channel where cattle have very limited or no access, such as steep-walled canyons or areas in limited grazing systems. Sites 16 and 21 are located along segments of channel in steep-walled canyons (Site 21) and in allotments with very limited periods of grazing and reduced numbers of cattle (Site 16). Site 3 is also a limited access site downstream from a pasture site. All these sites show a reduction in bacterial indicator concentrations from sites upstream.

For the management and land-use practices on Reynolds Creek and adjacent area, the fecal coliform concentration line of 50 counts/100 ml separates the pasture sites from the rangeland sites for all data collected over this period. Even at locations where cattle congregate for water and shade, such as at site 22, the mean value of the counts did not exceed 50. This indicates that the rangeland portion of Reynolds Creek is not the major contributor to bacterial indicators of stream pollution.

The geometric mean ($\bar{X}$) of all the data for all the sites was 54.70 with standard deviation of 40.72. However, without the data from site 1 the geometric mean was reduced to 43.67 and standard deviation of 18.80. This points out the significant impact that results from year around access of livestock to streams; in this case, an increase in fecal coliform counts of 14/100 mls.

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Chapter 5

VEGETATION AND SOILS

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Chapter 5

VEGETATION AND SOILS

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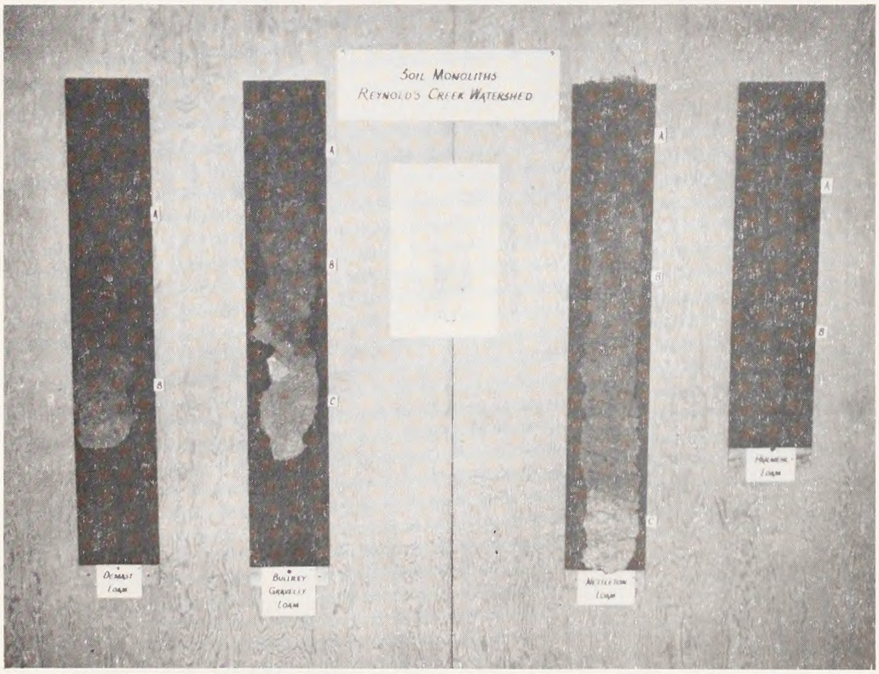
Wyoming Big Sagebrush



Soil Monoliths

INTRODUCTION

Four vegetation studies conducted on the Reynolds Creek Experimental Watershed were: 1) forage production, botanical composition, and ground cover as affected by excluding grazing; 2) species adaptability plantings; 3) comparison between the wheel-point, step-point, and point-frame cover sampling methods; and 4) herbage response after mechanical and herbicide treatment of big sagebrush in southwest Idaho (Schumaker and Hanson 1977). Studies one and two are reported in detail in this chapter and study three is reported in chapter 6. The fourth study has been published and therefore only a brief summary is included in this report. This chapter also includes a discussion of Reynolds Creek soils.

FORAGE PRODUCTION, BOTANICAL COMPOSITION, AND GROUND COVER AS AFFECTED BY EXCLUDING GRAZING

Study Areas

Nine study sites were located on the Reynolds Creek Experimental Watershed in southwestern Idaho (Figure 5.1). Site elevations ranged from 3885 feet at Flats to higher than 6840 feet at Reynolds Mountain, and associated average annual precipitation varied from 9.34 inches to 40.91 inches, respectively (Table 5.1). Drifting snow accumulations at Upper Sheep Creek and Reynolds Mountain sites increased plant available water. The precipitation distribution was similar for all sites, occurring primarily during winter through early summer (Figure 5.2).

Soils at the study sites were derived from basalt, sediments, granite, or rhyolite; soil textures varied from loam to gravelly loam (Table 5.2) (Stephenson 1977).

The primary plant species at each study site are listed in Table 5.3. All sites had a dense sagebrush (Artemisia tridentata subsp.) cover, except Flats, where shadscale (Atriplex confertifolia) was the major brush species.

Procedures

Fence exclosures were established at each study site to exclude livestock. The area around the exclosures was grazed as part of the existing allotment or pasture. Grazing intensities were usually moderate except at the Nettleton site where an intensive, heavy grazing treatment was imposed over a ten-day period each June. The annual yield, sampling plots on the grazed areas were protected by small wire cages, which were randomly located each spring prior to grazing.

Annual herbage yields were determined by the double-sampling, weight estimate method described by Wilm et al. (1944). Each year, two people estimated the green herbage weight, by species, within 20 randomly located, 9.6 ft^2 circular plots at each site--10 plots inside and 10 plots outside fenced exclosures. After the weight estimates were made, two plots were clipped by species for dry weight determination. Yield estimates were made at each site when bottlebrush squirreltail (Sitanion hysterix) had reached the seed set stage. Only the nonwoody portion of

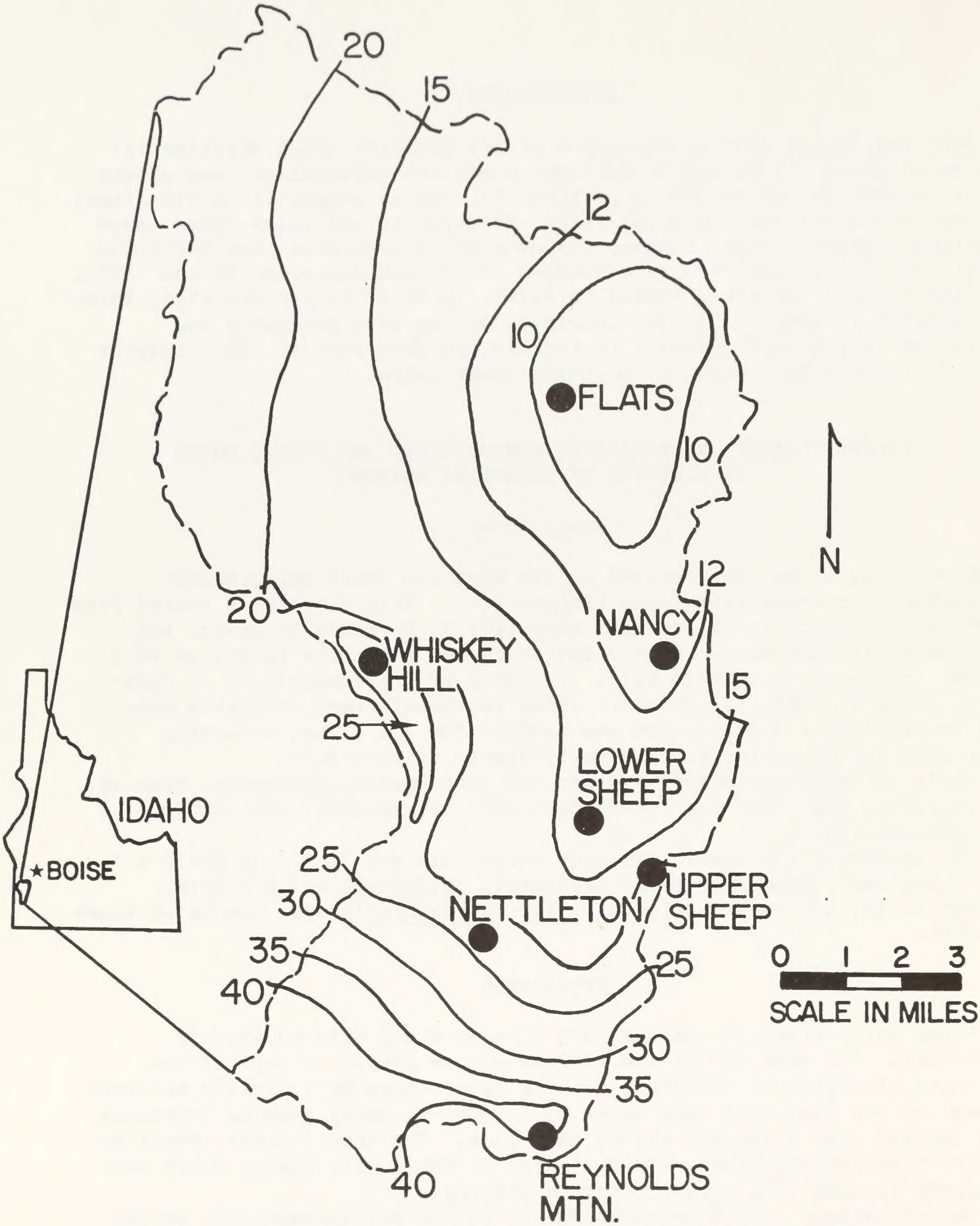


Figure 5.1.--Isohyetal map with the location of the nine study sites, Reynolds Creek Experimental Watershed, southwest Idaho. Numbers indicate inches of precipitation per year.

Table 5.1.--Elevation, annual precipitation, slope, aspect, and vegetation cover of study sites.

Site	Elevation (ft)	Slope (%)	Aspect of Slope	Precip. (1962-80)	Vegetation[1/] Basal Cover Percent
Flats	3885	5	N	9.34	34
Nancy Gulch	4600	8	NE	11.00	48
Nettleton	5000	25	W	21.93	56
Lower Sheep Creek	5400	16	NW	13.74	45
Whiskey Hill	5560	15	E	27.60	66
Upper Sheep Creek[2/] (sparse)	6100	33	SW	20.00	23
Upper Sheep Creek[3/] (dense)	6100	33	NE	20.00	84
Reynolds Mountain[2/] (sparse)	6870	5	SW	30.30	39
Reynolds Mountain[3/] (dense)	6840	6	NW	40.91	74

1/ Cover measurements on grazed treatment, Table 5.5.

2/ Snow removed by wind.

3/ Snow deposition zone.

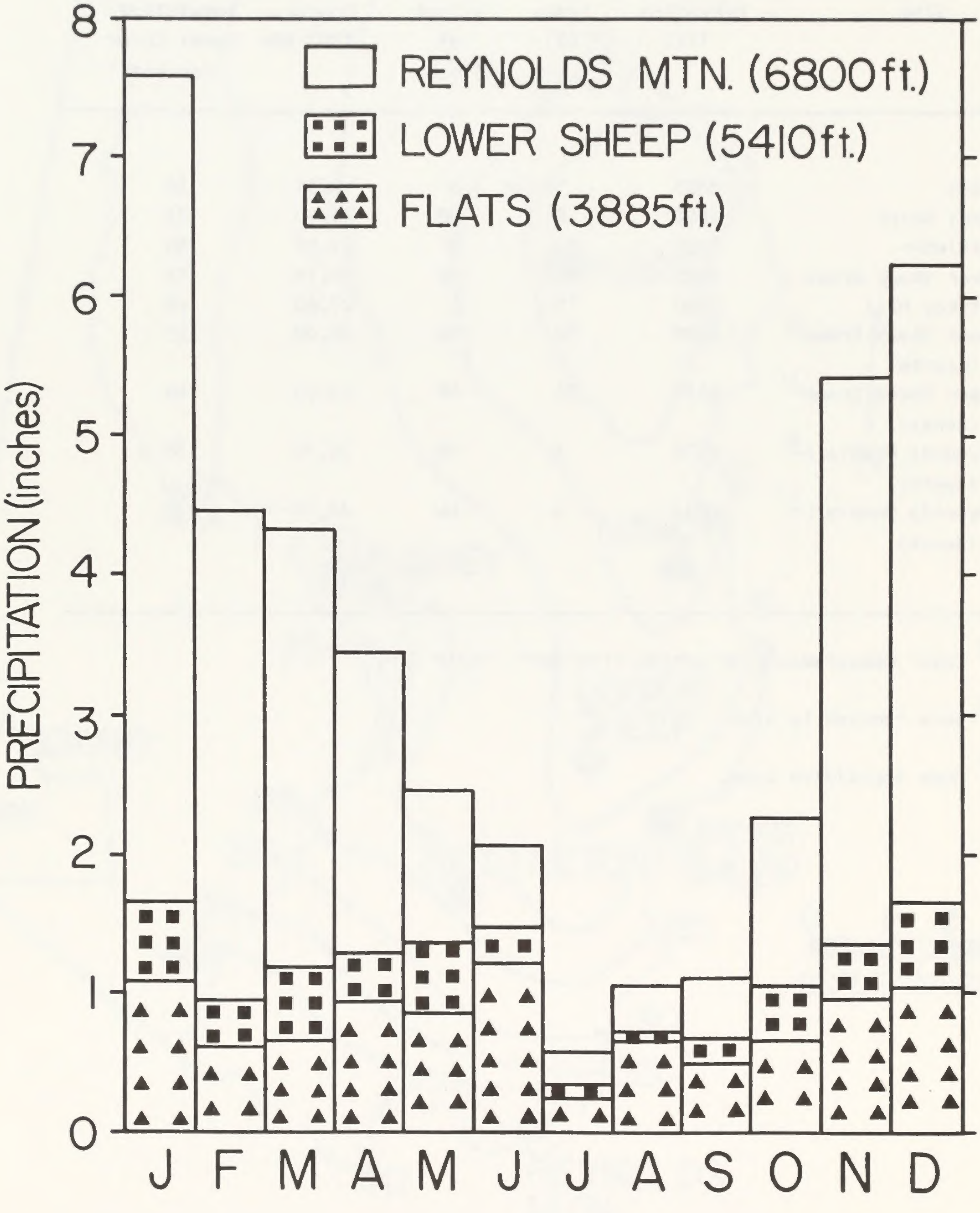


Figure 5.2.--Average monthly precipitation at Reynolds Mountain, Lower Sheep, and Flats sites.

Table 5.2.--Geologic material and soil characteristics at study sites.

Site	Geologic Material	Soils: Subgroup	Soils: Family	Soils: Series
Flats	Sedimentary	Typic Haplargids	Fine loamy	Nannyton loam
Nancy Gulch	Basalt	Xerollic Haplargids	Fine, montmorillonite, mesic	Glasgow loam
Nettleton	Basalt	Lithic Argixerolls	Loamy skeletal, mixed, mesic	Reywat - Bakeoven rocky, very stony loam
Lower Sheep Creek	Basalt	Calcic Argixerolls	Loamy skeletal, mixed, frigid	Searla gravelly loam
Whiskey Hill	Granite	Typic Haploxerolls	Coarse loamy, mixed, frigid	Takeuchi rocky coarse sandy loam
Upper Sheep Creek (sparse)	Basalt	Lithic Argixerolls	Loamy skeletal mixed, frigid	Gabica very rocky loam
Upper Sheep Creek (dense)	Basalt	Argic Pachic Cryoborolls	Fine loamy, mixed	Harmehl and Demast Loam
Reynolds Mountain (sparse)	Rhyolite	Pachic Cryoborolls	Fine loamy, mixed	Bullrey gravelly loam
Reynolds Moutain (dense)	Rhyolite	Pachic Cryoborolls	Fine loamy, mixed	Bullrey gravelly loam

Table 5.3.--List of primary plant species at study sites.

Plant species	Site								
	Flats	Nancy Gulch	Nettleton	Lower Sheep Creek	Whiskey Hill	Upper Sheep Creek (sparse)	Upper Sheep Creek (dense)	Reynolds Mt. (sparse)	Reynolds Mt. (dense)
Grasses and sedges									
Bearded bluebunch wheatgrass *Agropyron spicatum*		X	X	X	X	X			
Slender wheatgrass *Agropyron trachycaulum*							X		X
Big mountain brome *Bromus marginatus*							X		X
Cheatgrass brome *Bromus tectorum*	X	X	X		X				
Oniongrass *Melica bulbosa*							X		
Idaho fescue *Festuca idahoensis*					X		X	X	X
Nevada bluegrass *Poa nevadensis*							X		X
Sandberg bluegrass *Poa sandbergii*	X	X	X	X	X	X	X	X	
Bottlebrush squirreltail[1/] *Sitanion hystrix*	X	X	X	X	X	X	X	X	X
Needle-and-thread *Stipa comata*					X		X	X	X
Sedges *Carex* spp.							X	X	X
Forbs									
Western yarrow *Achillea millefolium lanulosa*					X		X	X	X
Low pussytoes *Antennaria dimorpha*		X				X			
Rose pussytoes *Antennaria rosea*								X	
Milkvetch *Astragalus* spp.				X		X			
Arrowleaf balsamroot *Balsamorhiza sagittata*					X				

Table 5.3.--List of primary plant species at study sites--Continued.

Plant species	Site								
	Flats	Nancy Gulch	Nettleton	Lower Sheep Creek	Whiskey Hill	Upper Sheep Creek (sparse)	Upper Sheep Creek (dense)	Reynolds Mt. (sparse)	Reynolds Mt. (dense)
Indian paintbrush *Castilleja* spp.								X	
Bastard toadflax *Comandra pallida*					X				
Hawksbeard *Crepis* spp.					X				
Sulfur eriogonum *Eriogonum umbellatum*					X		X		
Clasping pepperweed *Lepidium perforiatum*	X								
Lupine *Lupinus* spp.			X		X	X	X	X	X
Phlox *Phlox* spp.		X							
Cinquefoil *Potentilla arguta convallaria*							X		
Yellow salsify *Tragopogon dubius*			X						
Violet *Viola* spp.							X		X
Shrubs									
Low sagebrush *Artemisia arbuscula*				X		X			
Mountain big sagebrush *Artemisia tridentata vaseyana*							X	X	X
Wyoming big sagebrush *Artemisia tridentata wyomingensis*	X	X	X		X				
Shadscale *Atriplex confertifoila*	X								
Mountain low rabbitbrush *Chrysothamnus viscidiflorus lanceolatus*					X	X	X		
Mountain snowberry *Symphoricarpos oreophilus oreophilus*							X		X

1/ Indicator species for harvest.

the brush species was considered annual growth. All yields were reported on an air-dry weight of 12 percent moisture.

Basal and canopy cover were obtained from seven 100-point transects in both the grazed and ungrazed treatments at each site at the same time yield estimates were made. The point data were taken by the wheel-point method described by Tidmarsh and Havenga (1915), and von Broembsen (1965). A wheel-point contacted the ground every 2 feet along the sampling transect. Hits were recorded from ground up after the spoke was vertical. There could be a basal hit plus three overstory hits. All ground level hits were considered basal cover. When there were more than four hits including the basal hit, the first four from the ground up were recorded. If the same species was hit more than once per quadrat, only the first hit from the bottom was recorded. Plant hits with the wheel-point method were recorded when any part of the pin contacted a plant part. In 1974, 1975, 1978, and 1979, additional transects were taken near the end of the grazing season.

Differences are considered statistically significant for $P < .05$.

Grazed and Ungrazed: Herbage Yields

Average yearly herbage yields from within (ungrazed), and outside the exclosures (grazed annually) are listed in Table 5.4. Record lengths vary from 8 to 10 years among the study sites, but all data were obtained during the 11 year-period, 1971 through 1981. The yields listed in Table 5.4 are for both total herbage yield and yield excluding shrub herbage.

The total average yield from inside the exclosures varied between 533 lb/acre and 1743 lb/acre. Both of these yields were at the Upper Sheep site and indicate the effect of exposure. The Upper Sheep Creek (dense) site is on a north facing slope in an area where snow blows onto the site. The other site is across the valley from the (dense) site on a south facing slope where the snow is blown off. The average yields on the five ungrazed sites where the annual precipitation was less than 14 inches per year and at the two sites where the snow was blown off were between 533 and 671 lb/acre. The average ungrazed yield at the other four sites ranged between 1073 and 1743 lb/acre.

There were only three grazed and ungrazed mean yields that were significantly different. The total yield on the grazed treatment at the Flats was significantly greater, and the ungrazed treatment of nonshrub yields was greater at Lower Sheep Creek and Nettleton. In general, grazing had little effect on herbage production. Also, after 11 years of study, there was no noticeable trend developing toward greater or lesser nonshrub herbage yields on the ungrazed or grazed treatments, except at the Nettleton site which will be discussed later. Because of the large sampling error, year-to-year yield variations were large and mean differences had to be large before statistically significant differences could be obtained.

There was a large shrub yield decrease from 1977 through 1979 at the Upper Sheep Creek and Reynolds Mountain dense sites. This change was due to the winterkill of mountain big sagebrush (Artemesia tridentata vaseyana) during the low snow cover winter of 1976-77 (Hanson et al. 1982). As can be seen from Table 5.4, a considerable amount of the sagebrush was also killed on the Reynolds Mountain sparse site, but this sagebrush is not normally completely covered and was less susceptible to winterkill from exposure than was the sagebrush under the deep snowpacks.

Table 5.4.--Herbage yield of the ungrazed and grazed areas (lb/acre, air dry weight).

			71	72	73	74	75	76	77	78	79	80	81	Mean
Flats	Total	Ungrazed	555	424	---[1]	558	436	446	193	1958	466	1005	---	671[2]
		Grazed	850	663	---	649	709	592	263	2059	630	1060	---	831
	No Shrubs[3]	Ungrazed	510	216	---	398	343	367	69	1343	303	744	---	477
		Grazed	664	207	---	443	522	398	101	735	291	641	---	445
Nancy Gulch	Total	Ungrazed	403	676	1018	977	607	564	198	590	568	583	---	618
		Grazed	603	453	1201	893	666	758	465	835	963	823	---	766
	No Shrubs	Ungrazed	373	230	648	377	450	398	68	361	299	213	---	342
		Grazed	392	139	523	501	425	500	81	315	389	260	---	352
Nettleton	Total	Ungrazed	1950	536	1017	974	1513	878	889	1745	780	---	1577	1186
		Grazed	1286	472	1353	1057	803	931	459	1210	621	---	1149	934
	No Shrubs	Ungrazed	1790	388	974	911	1106	724	811	1476	694	---	376	925[2]
		Grazed	1182	332	886	917	425	810	425	765	525	---	149	642
Lower Sheep Creek	Total	Ungrazed	851	339	---	599	688	541	138	1178	525	---	---	607
		Grazed	818	439	---	648	686	386	350	744	717	---	---	599
	No Shrubs	Ungrazed	699	156	---	313	339	261	66	471	272	---	---	322[2]
		Grazed	501	143	---	105	247	156	53	147	228	---	---	198
Whiskey Hill	Total	Ungrazed	---	805	878	1075	1043	830	1092	1804	1054	---	---	1073
		Grazed	---	1359	887	768	1752	1029	1758	1789	1413	---	---	1344
	No Shrubs	Ungrazed	---	211	393	617	678	672	588	1217	817	---	---	649
		Grazed	---	355	300	368	673	638	419	789	633	---	---	522
Upper Sheep Creek (sparse)	Total	Ungrazed	558	614	---	351	521	302	688	774	452	---	---	533
		Grazed	593	488	---	335	567	755	608	588	663	---	---	575
	No Shrubs	Ungrazed	419	165	---	81	155	99	224	540	178	---	---	233
		Grazed	467	164	---	58	118	200	109	173	322	---	---	201
Upper Sheep Creek (dense)	Total	Ungrazed	2114	1630	2164	1508	1423	611	1492	3326	1419	---	---	1743
		Grazed	2850	1584	1170	2104	1266	1195	1451	2664	1633	---	---	1768
	No Shrubs	Ungrazed	1689	386	686	441	407	253	1321	3224	1348	---	---	1084
		Grazed	2334	642	590	915	502	516	1317	2039	1217	---	---	1125
Reynolds Mountain (sparse)	Total	Ungrazed	698	451	---	596	830	789	447	655	486	---	---	619
		Grazed	926	361	---	858	688	609	605	692	690	---	---	679
	No Shrubs	Ungrazed	659	130	---	266	346	423	318	427	346	---	---	364
		Grazed	895	217	---	386	385	290	468	377	435	---	---	432
Reynolds Mountain (dense)	Total	Ungrazed	1282	1923	2026	1460	1746	589	884	2196	1121	---	---	1470
		Grazed	1515	985	1347	1203	1732	1577	1118	1304	864	---	---	1294
	No Shrubs	Ungrazed	906	365	425	474	349	266	763	958	876	---	---	598
		Grazed	914	278	255	327	434	249	410	1101	685	---	---	517

[1] Not sampled that year.

[2] Means are significantly different at the 0.05 probability level.

[3] The yields of shrub species not included.

Grazing treatments at the Nettleton site consisted of no grazing within the exclosure and very heavy grazing adjacent to the exclosure. The heavily grazed area was grazed about 10 days each June from 1971 through 1979, and was not grazed in 1980 or 1981. Although not statistically different, yields from the heavily grazed area were consistently lower than from the nongrazed area from 1977 to 1981. This trend indicated that heavy grazing reduces herbage yields within the time frame of this study. However, at sites where stocking rates were allotted according to the Bureau of Land Management, USDI, management plan, there are few indications of herbage yield differences in the grazed and ungrazed treatments.

Grazed and Ungrazed: Cover

Basal cover is summarized for the nine sites in Table 5.5 and the annual basal cover measurements are listed in Volume III, Section E, Tables E.1.1 - E.1.9. Average grass cover on the ungrazed treatments was significantly greater than on the grazed treatment only on the two Upper Sheep Creek sites and the dense site at Reynolds Mountain. Forbs accounted for 11 percent or less of basal cover at all sites, and were nearly the same in both treatments, except at the Upper Sheep Creek dense site where there were significantly more forbs on the grazed than on the ungrazed treatment. Average shrub cover accounted for four percent or less of the basal cover at all sites.

Average litter cover ranged from 13 percent on the grazed Upper Sheep Creek (sparse) site to 72 percent on the ungrazed Upper Sheep Creek (dense) site. The average litter cover was significantly greater on the ungrazed than the grazed plots at only the Upper Sheep Creek (sparse) and Nettleton sites. There was 18 percent less litter cover on the Nettleton grazed treatment than on the ungrazed, which indicates that the heavy grazing decreased litter cover. There was 10 percent or less litter cover difference between the grazed and ungrazed treatments at the other sites. Average bare ground ranged from 55 percent on the grazed area at the Flats to only 7 percent on the ungrazed area at Upper Sheep Creek (dense) and was significantly greater on the grazed than on the ungrazed at four of the nine study sites.

Although the ungrazed plots generally had more herbage and litter cover and less bare ground than the grazed plots, there were only a few differences that were significant. However, at the Nettleton site, litter cover was significantly greater on the ungrazed treatment, and bare ground was significantly greater on the grazed treatments. Results are similar to that reported by Johnson et al. 1980.

Basal cover information was obtained in late summer for four years at the nine sites to determine cover conditions prior to fall and winter precipitation. These data are presented in Volume III, Section E, Table E.1.10, and indicated that there was less grass cover, more litter cover, and less bare ground in the fall than at peak standing crop.

Basal and first hit canopy cover of selected species for 1972 through 1980

One of the reasons for establishing the grazing study areas in 1971 on the Reynolds Creek Watershed was to determine what effect excluding grazing would have on species composition. Table 5.6 and 5.7 summarize basal and canopy cover of selected species at each of the nine study sites for the period 1972-1980.

Table 5.5.--Average basal cover in percent at time of peak standing crop.

	Grasses		Forbs		Shrubs		Litter		Rock		Bare Ground	
	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed
Flats	9[a][1/]	6[a]	2	3	1	1	34[a]	24[a]	5[a]	11[b]	49[a]	55[a]
Nancy Gulch	9[a]	10[a]	10[a]	11[a]	1	1	29[a]	26[a]	17[a]	17[a]	34[a]	35[a]
Nettleton	18[a]	16[a]	2	2	1	1	55[a]	37[b]	7[a]	13[b]	17[a]	31[b]
Lower Sheep Creek	13[a]	14[a]	9[a]	6[a]	2	2	26[a]	23[a]	28[a]	31[b]	22[a]	24[a]
Whiskey Hill	12[a]	11[a]	5	3	2	3	49[a]	49[a]	5[a]	5[a]	27[a]	29[a]
Upper Sheep Creek (sparse)	7[a]	6[b]	2	1	4[a]	3[a]	18[a]	13[b]	33[a]	35[b]	36[a]	42[b]
Upper Sheep Creek (dense)	14[a]	8[b]	5[a]	9[b]	1	1	72[a]	66[a]	1	1	7[a]	15[b]
Reynolds Mountain (sparse)	9[a]	8[a]	7[a]	8[a]	1	1	19[a]	22[a]	48[a]	42[b]	16[a]	19[b]
Reynolds Mountain (dense)	15[a]	9[b]	8[a]	7[a]	2	1	55[a]	57[a]	3[a]	4[a]	17[a]	22[a]

[1/] Means from each study site within each cover type with the same letter are not significantly different at the 0.05 probability level. Means within each cover type without letters were not analyzed statistically because of the small number of hits.

Table 5.6.--Basal cover of selected species from nine study sites on Reynolds Creek Watershed, 1972 through 1980.

Site	Treatment	Species	72	73	74	75	76	77	78	79	80
Flats	Ungrazed	Bottlebrush squirreltail	2.6	0.3	2.4	1.6	0.3	2.7	1.9	2.0	0.3
		Cheatgrass	8.1	2.1	14.8	15.3	0.1	0.3	18.7	2.0	1.1
		Shadscale	---	0.9	1.0	0.6	0.1	2.4	1.1	0.4	0.0
	Grazed	Bottlebrush squirreltail	4.1	0.1	1.7	1.0	---	2.0	0.4	0.6	0.3
		Cheatgrass	7.7	1.7	7.3	14.1	0.7	0.3	8.3	1.4	4.0
		Shadscale	0.1	0.7	1.2	1.1	---	0.4	0.7	0.4	0.3
Nancy Gulch	Ungrazed	Bottlebrush squirreltail	2.7	0.8	1.7	1.7	0.4	1.4	1.0	0.9	0.4
		Sandberg bluegrass	8.9	10.4	16.0	9.5	2.6	3.9	7.3	8.3	2.9
		Big sagebrush	---	0.5	0.7	1.4	0.3	2.0	1.4	1.0	0.6
	Grazed	Bottlebrush squirreltail	2.4	0.2	1.0	0.6	---	0.4	0.1	0.1	0.6
		Sandberg bluegrass	14.9	6.2	13.3	11.0	2.6	3.3	8.9	9.6	6.7
		Big sagebrush	0.1	0.8	0.9	1.0	0.3	1.6	1.0	1.0	0.6
Nettleton	Ungrazed	Bottlebrush squirreltail	2.6[1]	3.0	2.6	0.4	1.0	2.0	1.0	0.6	0.7
		Sandberg bluegrass	10.1	13.4	14.7	12.3	2.6	10.1	2.9	3.0	1.7
		Cheatgrass	11.3	5.4	8.1	23.9	0.7	10.1	3.9	0.1	0.1
		Big sagebrush	---	---	0.6	1.4	0.6	1.0	0.7	0.0	0.0
	Grazed	Bottlebrush squirreltail	2.6[1]	3.2	0.4	0.4	0.4	3.0	1.3	0.4	0.0
		Sandberg bluegrass	10.1	21.0	9.4	13.2	3.0	14.0	14.7	12.4	6.4
		Cheatgrass	11.3	4.7	0.4	5.3	---	4.0	2.9	0.0	0.1
		Big sagebrush	---	0.5	0.3	2.1	0.9	1.0	0.9	0.0	0.0
Lower Sheep Creek	Ungrazed	Sandberg bluegrass	13.9	NA[2]	17.7	12.0	3.9	29.9	7.9	9.3	0.3
		Low sagebrush	0.4	NA	2.6	6.0	1.0	1.3	1.9	1.3	0.1
	Grazed	Sandberg bluegrass	14.7	NA	16.9	15.0	5.9	29.9	12.6	11.9	0.4
		Low sagebrush	0.1	NA	1.7	4.4	0.7	2.1	3.0	3.1	0.3
Whiskey Hill	Ungrazed	Bottlebrush squirreltail	2.0	---	1.6	2.0	0.3	4.2	0.6	1.2	0.2
		Sandberg bluegrass	5.0	2.7	3.6	1.2	1.3	3.0	1.8	2.8	0.6
		Big sagebrush	0.3	2.4	0.8	0.2	0.4	0.8	0.6	0.4	0.0
	Grazed	Bottlebrush squirreltail	3.3	3.3	1.6	2.0	0.7	2.4	0.8	0.2	0.0
		Sandberg bluegrass	9.9	10.4	3.2	6.4	1.4	4.8	2.8	4.2	0.6
		Big sagebrush	0.3	0.4	1.6	2.0	2.1	2.4	1.8	1.0	0.4
Upper Sheep Creek (sparse)	Ungrazed	Sandberg bluegrass	12.1	NA	7.0	5.3	3.4	11.3	6.9	7.1	0.7
		Low sagebrush	1.1	NA	1.9	9.1	1.1	7.1	1.9	1.3	0.3
	Grazed	Sandberg bluegrass	8.1	NA	5.7	3.4	3.0	8.6	7.0	5.4	1.0
		Low sagebrush	0.4	NA	2.3	4.0	0.7	4.0	1.3	0.7	0.0
Upper Sheep Creek (dense)	Ungrazed	Bottlebrush squirreltail	9.6	2.1	6.6	1.0	0.4	3.2	4.4	0.7	0.0
		Needlegrass	8.6	3.5	3.6	1.6	0.2	1.3	3.1	0.1	0.1
		Big sagebrush	--	2.3	2.9	0.1	---	0.4	0.7	1.0	0.1
	Grazed	Bottlebrush squirreltail	8.8	1.7	2.3	0.2	---	1.9	2.0	1.4	0.0
		Needlegrass	10.0	3.6	1.4	2.6	---	0.6	2.6	1.8	0.0
		Big sagebrush	---	2.9	1.0	2.8	---	0.3	0.3	0.0	0.1
Reynolds Mountain (sparse)	Ungrazed	Sandberg bluegrass	---	NA	0.1	---	0.9	3.7	0.4	2.0	0.1
		Sedge	4.1	NA	1.9	4.3	7.9	0.3	1.7	1.0	0.0
		Idaho fescue	3.1	NA	1.7	2.4	1.1	4.4	2.6	2.7	0.6
		Big sagebrush	---	NA	0.7	2.6	1.0	---	0.4	0.3	0.0
	Grazed	Sandberg bluegrass	---	NA	---	---	---	6.0	2.1	2.0	0.0
		Sedge	3.0	NA	---	2.7	6.1	0.3	1.9	0.9	0.4
		Idaho fescue	1.1	NA	2.1	2.1	2.3	1.6	0.1	1.0	0.6
		Big sagebrush	---	NA	0.9	3.9	0.6	---	0.1	0.4	0.1
Reynolds Mountain (dense)	Ungrazed	Needlegrass	4.7	4.0	2.0	2.0	0.3	0.8	2.4	0.4	0.0
		Bluegrass	2.8	1.7	---	0.2	0.5	3.8	3.2	0.8	0.1
		Big mountain brome	3.6	4.2	1.2	0.6	1.0	2.4	1.2	0.8	0.0
		Lupine	6.3	4.0	2.0	1.4	13.1	0.4	0.2	0.2	0.0
		Big sagebrush	---	4.0	0.8	3.4	2.8	0.2	0.6	0.8	0.0
	Grazed	Needlegrass	1.9	---	1.2	5.0	2.3	0.4	0.2	0.2	0.0
		Bluegrass	4.0	1.3	1.2	1.0	1.8	1.0	0.2	0.8	0.0
		Big mountain brome	5.0	0.4	1.6	1.4	2.3	1.4	0.8	1.2	0.0
		Lupine	2.1	0.8	2.2	1.2	12.4	0.2	0.4	0.6	0.0
		Big sagebrush	0.1	3.4	0.6	3.2	0.8	0.2	---	0.2	0.1

1/ Point data taken before grazing study started.

2/ Data not available.

Table 5.7.--First hit canopy cover of selected species from nine study sites on Reynolds Creek Watershed, 1972 through 1981.

Site	Treatment	Species	72	73	74	75	76	77	78	79	80	81
Flats	Ungrazed	Bottlebrush squirreltail	1.0	2.8	5.8	5.0	3.4	3.3	7.8	17.6	10.6	---
		Cheatgrass	25.2	30.0	20.0	21.1	45.8	0.3	27.5	8.0	20.6	---
		Shadscale	11.9	0.6	7.6	4.4	7.8	9.7	8.4	5.1	10.0	---
	Grazed	Bottlebrush squirreltail	0.7	0.6	3.3	1.5	0.3	1.4	1.4	2.3	3.5	---
		Cheatgrass	18.6	16.0	10.6	23.5	47.4	0.1	13.7	2.8	10.6	---
		Shadscale	13.6	9.2	7.0	3.4	6.7	5.5	6.7	4.8	6.3	---
Nancy Gulch	Ungrazed	Bottlebrush squirreltail	2.8	2.7	4.0	3.9	3.8	1.7	4.3	3.0	3.0	---
		Sandberg bluegrass	17.1	14.9	16.9	28.5	45.2	3.7	14.9	15.2	21.3	---
		Big sagebrush	18.3	15.6	8.4	12.3	9.9	10.9	10.2	8.6	15.9	---
	Grazed	Bottlebrush squirreltail	1.2	0.9	1.0	1.2	2.3	0.5	0.8	1.1	1.1	---
		Sandberg bluegrass	19.0	11.2	13.2	27.8	37.2	3.6	15.7	14.8	20.0	---
		Big sagebrush	17.8	12.6	9.4	13.0	12.6	9.5	6.7	12.7	19.8	---
Nettleton	Ungrazed	Bottlebrush squirreltail	6.6	4.1	6.7	0.7	7.3	4.0	8.1	9.6	8.7	13.0
		Sandberg bluegrass	18.9	19.3	20.5	26.1	28.0	9.1	8.7	3.0	15.1	34.4
		Cheatgrass	16.1	7.7	17.6	25.1	20.2	29.3	49.6	6.1	6.7	17.8
		Big sagebrush	11.1	0.5	5.7	6.6	8.4	6.1	5.2	0.7	6.0	6.3
	Grazed	Bottlebrush squirreltail	6.6	2.0	1.8	1.3	4.5	3.0	5.9	5.7	0.1	7.6
		Sandberg bluegrass	18.9	17.1	10.0	31.0	50.3	14.0	45.8	23.1	41.1	71.2
		Cheatgrass	16.1	1.5	5.0	8.8	6.9	15.0	20.0	3.0	4.0	4.6
		Big sagebrush	11.1	5.5	5.3	12.9	6.0	7.0	6.3	0.9	7.3	4.6
Lower Sheep Creek	Ungrazed	Sandberg bluegrass	20.0	NA	15.5	19.0	30.2	21.1	10.5	10.6	16.0	---
		Low sagebrush	30.0	NA	19.3	26.1	28.8	16.3	23.9	23.8	23.1	---
	Grazed	Sandberg bluegrass	21.5	NA	14.1	15.6	38.4	16.6	11.5	11.6	18.5	---
		Low sagebrush	25.9	NA	19.5	25.1	24.4	21.4	21.9	24.2	23.8	---
Whiskey Hill	Ungrazed	Bottlebrush squirreltail	1.0	0.2	6.4	4.4	5.2	5.0	7.6	2.0	1.6	---
		Sandberg bluegrass	4.4	3.7	4.8	3.0	9.1	1.8	2.8	2.8	4.4	---
		Big sagebrush	39.8	29.0	14.8	27.4	17.6	20.8	14.2	13.4	26.6	---
	Grazed	Bottlebrush squirreltail	1.2	1.4	6.7	3.4	4.7	4.6	5.2	0.6	1.2	---
		Sandberg bluegrass	4.4	4.3	5.2	5.8	4.3	3.8	4.6	5.6	4.8	---
		Big sagebrush	40.4	30.8	15.8	30.0	29.2	26.4	19.6	16.8	28.4	---
Upper Sheep Creek (sparse)	Ungrazed	Sandberg bluegrass	14.5	NA	9.4	9.6	22.1	10.7	11.7	12.6	17.7	---
		Low sagebrush	24.9	NA	19.8	18.7	23.3	23.3	22.6	18.4	24.8	---
	Grazed	Sandberg bluegrass	9.5	NA	6.0	8.7	19.5	11.6	13.2	13.0	14.5	---
		Low sagebrush	18.7	NA	13.6	17.3	16.2	19.0	18.5	15.9	21.4	---
Upper Sheep Creek (dense)	Ungrazed	Bottlebrush squirreltail	6.0	4.6	9.5	6.9	4.4	14.4	15.7	4.2	1.0	---
		Needlegrass	2.1	5.8	5.3	5.8	2.4	4.2	9.5	0.9	0.5	---
		Big sagebrush	47.4	30.4	29.9	30.5	27.2	8.2	7.1	6.6	13.1	---
	Grazed	Bottlebrush squirreltail	2.1	1.1	1.7	0.8	0.4	3.5	8.2	6.8	0.4	---
		Needlegrass	1.2	3.0	0.8	3.4	1.2	3.5	4.7	0.3	0.0	---
		Big sagebrush	45.8	25.2	35.0	38.2	39.4	4.9	3.2	2.6	5.0	---
Reynolds Mountain (sparse)	Ungrazed	Sandberg bluegrass	---	NA	0.1	---	---	3.3	2.0	2.5	4.4	---
		Sedge	5.1	NA	3.0	4.1	9.4	0.7	3.8	2.3	5.7	---
		Idaho fescue	4.2	NA	3.2	3.6	2.0	3.5	8.9	4.7	6.9	---
		Big sagebrush	22.7	NA	14.3	17.0	18.6	9.4	9.4	9.5	14.8	---
	Grazed	Sandberg bluegrass	---	NA	---	---	---	6.2	4.8	4.4	5.9	---
		Sedge	4.2	NA	---	2.5	5.3	0.4	2.9	1.7	11.6	---
		Idaho fescue	2.9	NA	2.1	3.5	4.4	1.7	6.1	3.1	4.4	---
		Big sagebrush	22.4	NA	10.3	15.1	22.2	8.9	7.8	9.9	10.2	---
Reynolds Mountain (dense)	Ungrazed	Needlegrass	2.3	0.8	2.4	4.8	0.8	2.0	6.0	2.4	0.0	---
		Bluegrass	0.8	0.6	---	1.2	1.8	5.0	5.6	4.2	2.6	---
		Big mountain brome	1.3	1.3	1.6	2.2	5.9	11.2	15.0	7.6	11.2	---
		Lupine	7.8	11.2	10.4	11.4	12.0	8.0	11.2	11.2	7.2	---
		Big sagebrush	59.4	48.2	45.6	42.2	58.6	10.6	16.0	15.2	17.8	---
	Grazed	Needlegrass	2.3	0.6	1.0	5.8	1.0	1.0	3.4	0.8	0.0	---
		Bluegrass	2.3	1.0	1.2	2.0	1.0	4.8	3.8	3.2	3.0	---
		Big mountain brome	4.4	1.5	2.8	1.8	2.3	20.0	30.0	12.8	11.6	---
		Lupine	4.1	9.0	8.8	8.6	11.6	18.0	7.8	7.4	6.4	---
		Big sagebrush	48.4	43.0	32.2	49.2	61.0	6.4	7.8	8.2	11.0	---

As can be seen from these tables, no measurable changes in species composition developed due to fencing the plots, except at the Nettleton plots. Here cheatgrass basal cover was greater on the ungrazed plot and the Sandberg bluegrass cover was greater on the grazed plot. Canopy cover of Bottlebrush squirreltail was greater on the ungrazed than the grazed treatment, but ground cover was about the same, which indicates that the plants were more vigorous under no grazing. The cover differences at Nettleton were associated with the very heavy grazing on the grazed plot, and no grazing on the other plot.

The forb and brush cover at each site did not show any trend toward changing species composition due to fencing. The sagebrush kill during the winter of 1976 and 1977 is very evident in the canopy cover data on the Upper Sheep Creek (dense) and the Reynolds Mountain (dense) sites.

Frequency of Occurrence

The change in frequency of occurrence over time is often used as an indicator of vegetation response to grazing. The frequency of occurrence values listed in Table 5.8 and in Volume III, Section E, Tables E.1.11 through E.1.19 are the average of the years of available data at each study site. The occurrence values of only the ungrazed plots were included because some of the grazed treatments were grazed prior to sampling each year.

On the ungrazed treatment at the Flats site, Bottlebrush squirreltail was the only species to increase in frequency following exclusion from grazing. At the Nettleton site, Sandberg bluegrass frequently decreased on the ungrazed plot and Bottlebrush squirreltail increased following exclusion of grazing. Frequency of occurrence of Idaho fescue increased on the ungrazed area during the nine years at the Whiskey Hill site. This was the only noticeable change at this site.

There were several changes at the Upper Sheep Creek (dense) site, and the two sites at Reynolds Mountain, some of which were due to the winterkill of Mountain big sagebrush during the 1976-77 winter. The frequency of occurrence of slender wheatgrass and forbs increased and big sagebrush decreased on both the grazed and nongrazed areas (Volume III, Section E, Tables E.1.17 - E.1.19). At Reynolds Mountain (sparse), the only noticeable change was the decrease of big sagebrush after the 1976-77 big sagebrush winterkill. Big mountain brome and forbs increased on both the grazed and nongrazed treatments of Reynolds Mountain (dense) after the sagebrush winterkill.

REYNOLDS CREEK SPECIES ADAPTABILITY PLANTINGS

Introduction

In cooperation with Stephen Monsen (Botanist/Biologist) and Nancy Shaw (Botanist) of the USDA, Forest Service, Intermountain Forest and Range Experiment Station, Boise, Idaho, adaptability planting sites were established at three locations in the Reynolds Creek drainage in October 1974 and May 1975. Plantings were established at different elevations to determine the species and strains best adapted to each site. List of species seeded at each location are shown in Tables 5.9, 5.10, and 5.11.

Table 5.8.--Average frequency of occurrence[1/] at time of peak standing crop (for period of record).

	Total Ungrazed	Grasses Ungrazed	Forbs Ungrazed	Shrubs Ungrazed
Flats	56	35	11	10
Nancy Gulch	60	31	14	15
Nettleton	94	64	17	13
Lower Sheep Creek	76	30	21	25
Whiskey Hill	102	40	32	30
Lower Sheep Creek (sparse)	62	21	11	30
Upper Sheep Creek (dense)	118	52	26	40
Reynolds Mountain (sparse)	57	20	21	16
Reynolds Mountain (dense)	113	110	38	37

[1/] Frequency of occurrence is the total number of hits divided by the number of point quadrats (pins) where not more than one hit per species was recorded for each point quadrat.

Table 5.9.--Species list for plantings in Flats Nursery.

Scientific Name	Source	Scientific Name	Source
GRASSES		FORBS	
Agropyron cristatum x A. desertorum	Logan ARS	Achillea millefolium lanulosa	Reynolds Creek
Agropyron cristatum fairway	Colorado, Commercial	Linum lewisii	Snow College farm
Agropyron dasystachyum	Aberdeen PMC	Sanguisorba magnolii	Spain PI 319091
Agropyron dasystachyum x A. caespitosum	Logan ARS	Sanguisorba minor	NK Oregon Commercial
Agropyron desertorum	Montana	Sanguisorba muricatum	Spain PI 319094
Agropyron desertorum	Montana (Nordan)	Tragopogon porrifolius	East of Boise
Agropyron elmeri	Commercial		
Agropyron intermedium	Wyoming (Oahe)	TREES AND SHRUBS	
Agropyron intermedium	Commercial (Amur)		
Agropyron intermedium	Commercial (Tegmar)	Artemisia tridentata vaseyana	Reynolds Creek
Agropyron repens x A. cristatum	Logan ARS	Atriplex canescens	Jackson Springs, Utah
Agropyron repens x A. desertorum	Logan ARS	Atriplex canescens	Keans Canyon, Utah
Agropyron riparium	Commercial (Sodar)	Atriplex canescens	Panaca, Nevada
Agropyron sibiricum	Idaho	Atriplex canescens	Huntington, Utah
Agropyron smithii	Montana, Commercial	Atriplex canescens	Ephraim
Agropyron spictatum	Montana, Commercial	Atriplex canescens	Big Bear Lake, California
Agropyron trachycaulum	Montana, Commercial	Atriplex canescens	Bridger, Montana
Agropyron trichophorum	Colorado (Luna)	Atriplex canescens	North Flagstaff
Agropyron trichophorum	Idaho (Topar)	Atriplex canescens	Reynolds Creek
Dactylis glomerata	Ephraim dryland form	Atriplex confertifolia	Reynolds Creek
Dactylis glomerata	Yugoslavia PI 251112	Chrysothamnus nauseosus	Reynolds Creek
Elymus cinereus	East Boise, Dry Creek	Chrysothamnus vicidiflorus	Reynolds Creek
Elymus junceus	Mandan, N. Dakota (vinall)	Ephedra nevadensis	Pine Valley, Utah
Elymus junceus	Tetonia, Idaho	Ephedra viridis	Manti, Utah
Oryzopsis hymenoides	Wyoming	Eurotia lanata	Hatch, Utah
Poa bulbosa	Pullman	Eurotia lanata	Reynolds Creek
Secale montanum	Turkey PI 274912	Purshia glandulosa	Lincoln Co., Nebraska
Secale montanum	Pullman SCS		

Table 5.10.--Species list of plantings in Nancy Gulch Nursery.

Scientific Name	Source	Scientific Name	Source
GRASSES		FORBS	
Agropyron cristatum x A. desertorum	Logan ARS	Achillea millefolium lanulosa	Reynolds Creek
Agropyron dasystachyum	Aberdeen PMC	Balsamorhiza sagittata	Coeur d'Alene
Agropyron dasystachyum x A. caespitosum	Logan ARS	Coronilla varia	Nebraska (Pennigift)
Agropyron desertorum	Montana	Coronilla varia	Commercial (Emerald)
Agropyron desertorum	Montana (Nordan)	Hedysarum boreale utahensis	R. Stewart
Agropyron elmeri	Commercial	Leptotaenia stipulacea	Iowa
Agropyron intermedium	Wyoming (Oahe)	Linum lewisii	Snow College farm
Agropyron intermedium	Washington (Greenar)	Medicago falcatus	Pullman
Agropyron intermedium	Commercial (Amur)	Medicago sativa	Idaho (Rhizoma)
Agropyron intermedium	Commercial (Tegmar)	Medicago sativa	Idaho (Nomad)
Agropyron repens x A. cristatum	Logan ARS	Medicago sativa	Idaho (Ladak)
Agropyron repens x A. desertorum	Logan ARS	Medicago sativa	Canada (Rambler)
Agropyron riparium	Commercial (Sodar)	Medicago sativa	Brookings, S. Dakota
Agropyron sibiricum	Idaho	Medicago sativa	Northrup King
Agropyron smithii	Montana, Commercial	Melilotus officinalis	Montana
Agropyron spicatum	Montana, Commercial	Onobrychis viciaefolia	Czeckoslovakia (Viva)
Agropyron trichophorum	Colorado (Luna)	Onobrychis viciaefolia	Montana (Eski)
Agropyron trichophorum	Idaho (Topar)	Sanguisorba magnolii	Spain PI 309091
Bromus inermis	Commercial	Sanguisorba minor	NK Oregon Commercial
Bromus inermis	GBRS (Northern)	Sanguisorba muricatum	Spain PI 319094
Bromus inermis	(Manchar) Commercial	Solidago gigantea	Reynolds Creek
Bromus marginatus	Pullman SCS (Bromar)	Trifolium fragiferum	California
Bromus tomentellus	SCS		
Calamagrostis epigelos	Commercial	TREES AND SHRUBS	
Dactylis glomerata	Commercial (Potomac)		
Dactylis glomerata	Ephraim dryland form	Amelanchier alnifolia	Bonneville Co., Idaho
Dactylis glomerata	Yugoslavia PI 251112	Amelanchier utahensis	Reynolds Creek
Elymus cinereus	East Boise, Dry Creek	Artemisia tridentata vaseyana	Reynolds Creek
Elymus junceus	Tetonia, Idaho	Cercocarpus montanus	Diamond Fork, Utah
Festuca ovina duriuscula	Idaho (Doran)	Chrysothamnus nauseosus	Reynolds Creek
Festuca ovina sulcata	PI 229450	C. viscidiflorus lanceolatus	Reynolds Creek
Oryzopsis hymenoides	Wyoming	Cowania mexicana stansburiana	American Fork, Utah

Table 5.10.--Species list of plantings in Nancy Gulch Nursery--Continued.

Scientific Name	Source	Scientific Name	Source
GRASSES (Continued)		TREES AND SHRUBS (Continued)	
Phleum pratense	Missouri	Cowania mexicana stansburiana	Pioche, Nevada
Poa pratensis	Commercial	Ephedra nevadensis	Pine Valley, Utah
Secale montanum	Turkey PI 274912	Ephedra viridis	Manti, Utah
Secale montanum	Pullman SCS	Eriogonum umbellatum	Shaffer Butte
Stipa viridula	Montana, Commercial	Erotia lanata	Hatch, Utah
		Prunus emarginata	Reynolds Creek
		Prunus virginiana melanocarpa	Reynolds Creek
		Purshia tridentata	Moffet Co., Colorado
		Purshia tridentata	Freemont Co., Utah
		Purshia tridentata	Boise
		Purshia tridentata	Eureka, Utah
		Purshia tridentata	Mono Lake, California
		Purshia tridentata	Washoe Co., Nevada
		Sambucus cerulea	Reynolds Creek

Table 5.11.--Species list of plantings in Reynolds Mountain Nursery.

Scientific Name	Source	Scientific Name	Source
GRASSES		FORBS	
Agropyron cristatum x A. desertorum	Logan ARS	Achillea millefolium lanulosa	Reynolds Creek
Agropyron cristatum Fairway	Colorado, Commercial	Balsamorhiza macrophylla	Cache Co., Utah
Agropyron dasystachyum	Aberdeen PMC	Balsamorhiza sagittata	Coeur d'Alene
Agropyron dasystachyum x A. caespitosum	Logan ARS	Coronilla varia	Nebraska (Pennigift)
Agropyron desertorum	Montana	Coronilla varia	Commercial (Emerald)
Agropyron desertorum	Montana (Nordan)	Ephedra nevadensis	Pine Valley, Utah
Agropyron elmeri	Commercial	Eriogonum	Grimes Creek, Idaho
Agropyron intermedium	Wyoming (Oahe)	Eriogonum umbellatum	Shaffer Butte
Agropyron intermedium	Washington (Greenar)	Hedysarum boreale utahensis	R. Stewart
Agropyron intermedium	Commercial (Amur)	Lesedeza stipulacea	Iowa
Agropyron intermedium	Commercial (Tegmar)	Linum lewisii	Snow College farm
Agropyron junceum	France PI 276566	Ligusticum porteri	Ephraim Canyon
Agropyron repens x A. desertorum	Logan ARS	Lotus corniculatus	Vermont (Broadleaf)
Agropyron riparium	Commercial (Sodar)	Lotus corniculatus	California (narrowleaf)
Agropyron sibiricum	Idaho	Lotus corniculatus	Canada (Empire)
Agropyron smithii	Montana, Commercial	Lotus corniculatus	Iowa
Agropyron spicatum	Montana (Commercial)	Lupinus sericeus	Cedar Mountain, Utah
Agropyron trachycaulum	Montana (Commercial)	Lupinus species	South of Twin Falls
Agropyron trichophorum	Colorado (Luna)	Medicago falcatus	Pullman
Agropyron trichophorum	Idaho (Topar)	Melilotus officinalis	Montana
Alopecurus pratensis	Commercial	Medicago sativa	
Bromus biebersteinii	Aberdeen SCS	Medicago sativa	
Bromus carinatus	Leadville, Colorado	Medicago sativa	
Bromus inermis	U.S.S.R. PI 315374	Medicago sativa	
Bromus inermis	U.S.S.R. PI 315378	Medicago sativa	
Bromus inermis	GBRS (Northern)	Medicago sativa	
Bromus inermis	Commercial (Manchar)	Onobrychis viciaefolia	Czechoslovakia (Viva)
Bromus inermis	Commercial (Lincoln)	Onobrychis viciaefolia	Montana (Eski)
Bromus marginatus	Pullman SCS (Bromar)	Osmorhiza occidentalis	Anderson Dam
Bromus tomentellus	SCS	Osmorhiza occidentalis	Middle Fork Payette
Calamagrostis epigeios	Commercial	Penstemon palmeri	

Table 5.11.--Species list of plantings in Reynolds Mountain Nursery--Continued.

Scientific Name	Source	Scientific Name	Source
GRASSES (Continued)		FORBS (Continued)	
Dactylis glomerata	Yugoslavia PI 251112	Sanguisorba magnolii	Spain PI 319091
Dactylis glomerata	Ephraim dryland form	Sanguisorba minor	NK Oregon, Commercial
Dactylis glomerata	Australia PI 209888	Solidago gigantea	Reynolds Creek
Elymus cinereus	East Boise, Dry Creek	Trifolium fragiferum	California
Festuca arundinacea	Commercial (Fawn)	Vicia villosa	Major's Flat, Utah
Festuca ovina duriuscula	Idaho (Doran)		
Festuca ovina	PI 229450	TREES AND SHRUBS	
Phleum pratense	Missouri		
Poa ampla	Washington, Commercial	Acer glabrum douglasii	Reynolds Creek
Poa compressa	Northrup King	Amelanchier alnifolia	Woodland, Utah
Poa pratensis	Commercial .	Amelanchier alnifolia	Bonneville Co., Idaho
Secale montanum	Pullman SCS	Amelanchier alnifolia	Reynolds Creek
Stipa viridula	Montana, Commercial	Amelanchier utahensis	Henryville, Utah
		Artemisia tridentata	Reynolds Creek
		Cercocarpus betuloides	Red Bluff, California
		Cercocarpus betuloides	Reynolds Creek
		Cercocarpus ledifolius	Reynolds Creek
		Cercocarpus ledifolius intricatus	Ephraim Canyon
		Cercocarpus montanus	Ephraim
		Cercocarpus montanus	Diamond Fork, Utah
		Cercocarpus montanus	Reynolds Creek
		Cercocarpus montanus	Pinto, Utah
		Ceanothus velutinous	Reynolds Creek
		Cowania mexicana stansburiana	American Fork, Utah
		Cowania mexicana stansburiana	Pioche, Nevada
		Holodiscus dumosus	Reynolds Creek
		Juniperus occidentalis	Reynolds Creek
		Prunus emarginata	Reynolds Creek
		Prunus virginiana melanocarpus	Reynolds Creek
		Purshia glandulosa	Lincoln Co., Nebraska
		Purshia tridentata	Moffet Co., Colorado
		Purshia tridentata	Fremont Co., Idaho

Table 5.11.--Species list of plantings in Reynolds Mountain Nursery--Continued.

Scientific Name	Source	Scientific Name	Source
		<u>TREES AND SHRUBS</u> (Continued)	
		<u>Purshia tridentata</u>	Boise
		<u>Purshia tridentata</u>	Eureka, Utah
		<u>Purshia tridentata</u>	Mono Lake, California
		<u>Rosa woodsii</u>	Reynolds Creek
		<u>Sambucus cerulea</u>	Reynolds Creek
		<u>Symphoricarpos oreophilus</u>	Bear Lake, Utah
		<u>Symphoricarpos oreophilus</u>	Reynolds Creek

Methods

Plantings were installed in existing exclosures at the Flats, Nancy Gulch, and Reynolds Mountain site (Figure 5.1) to exclude the impacts of livestock. Prior to planting, each site was disked to remove existing competition. Each species was then seeded into two plots each 10 feet in length. Following planting, annual ratings were made each year to determine plant survival and yearly growth rates. The first year after seeding, plant counts were taken early in the season to determine seedling emergence.

This report summarizes the performance of the planted species in 1981, seven years after seeding (Table 5.12). Field ratings were not taken in 1982, although the sites were inspected at this date and field notes were taken to record seasonal growth.

Of particular interest is the inclusion of a number of select strains or ecotypes which have been developed for range and wildland plantings. These include Paiute orchardgrass, hybrids of crested and fairway wheatgrass, Appar lewis flax, and selected strains of shrubs.

Results and Discussion

Flats Study Site

At Flats, 28 different grasses, 6 forbs, and 18 shrub accessions were planted. A number of different ecotypes of certain species were also seeded. With the exception of fourwing saltbush, seeds of nearly all species germinated and emerged. However, most seedlings disappeared within two years. Most shrub seedlings died during the first growing season.

Although the site supports a mixed stand of sagebrush and various salt desert species, these same shrubs are difficult to establish by artificial seeding. Shrubs that did persist included common winterfat, low rabbitbrush and green ephedra. About a dozen different collections of fourwing saltbush were planted, yet no seedlings were recorded for any plot.

Of the herbs seeded at this site, only a few grasses survived. Russian wildrye, desert wheatgrass, riparian wheatgrass, Sodar wheatgrass, the hybrid between crested and desert wheatgrass, and "Luna" pubescent wheatgrass are the only species to presist and remain productive. The survival and performance of these grasses under arid conditions has been well documented by other researchers. However, the response of the hybrid *Agropyron cristatum* x *A. desertorum* is of special interest. Other hybrids involving these and other species of *Agropyron* were also planted at the site, but failed to persist.

Most of the grasses seeded at this site established and did quite well until 1979 when nearly all died during this very dry year. Plants that persist today were also weakened by the dry year in 1979, but have recovered. Plants that died in 1979 were well established, mature stock, but could not persist through this extremely dry period.

The plants also suffered from a lack of moisture in 1976. All plants dried early in the season, and little regrowth occurred in the fall months.

Considerable competition occurred between the seeded plants and annual cheatgrass. Also, selective use was made of most forbs by rodents, deer,

Table 5.12.--Principal species to survive and grow at three planting locations, Reynolds Creek, Idaho.

Species	Source	Flats	Nancy Gulch	Reynolds Mt.
Grasses				
Agropyron cristatum x *A. desertorum*	Logan ARS	X[1/]	X	
Agropyron dasystachyum	Aberdeen PMS		X	X
Agropyron dasystacyum x *A. caespitosum*	Logan ARS		X	
Agropyron desertorum	Montana		X	
Agropyron desertorum	Montana (Nordan)	X	X*[2/]	
Agropyron elongatum	Commercial		X	
Agropyron intermedium	Wyoming (Oahe)		X	X*
Agropyron intermedium	Washington (Greenar)		X	X
Agropyron intermedium	Commercial (Amur)		X	X
Agropyron intermedium	Commercial (Tegmar)		X	X
Agropyron junceum	France PI 276566			X
Agropyron riparium	Commercial (Sodar)			X
Agropyron riparium	Commercial (Sodar)	X	X	X
Agropyron sibiricum	Idaho	X	X	X
Agropyron smithii	Montana (Commercial)		X	
Agropyron trichophorum	Colorado (Luna)	X	X*	X
Agropyron trichophorum	Idaho (Topar)		X	
Alopecurus pratensis	Commercial			X
Bromus inermis	USSR PI 315374			X
Bromus inermis	Commercial (Lincoln)		X	X*
Bromus inermis	Lincoln		X*	X
Bromus biebersteinii	Aberdeen PMC			X
Calamagrostis epigiosus	Commercial			X
Dactylis glomerata	Potomac		X	
Dactylis glomerata	Palute		X*	X
Dactylis glomerata	Yugoslavia PI 25112		X	
Elymus anereus	East Boise, Dry Creek			X
Elymus junceus	Tetonia, Idaho	X	X	
Festuca ovina duriuscula	Idaho (Doran)		X	X
Festuca ovina sulcata	PI 229450		X	
Festuca arundinacea	Commercial (Fawn)			X
Oryzopsis hymenoides	Wyoming		X	
Phleum pratensis	Missouri		X	
Poa compressa	Northrup King			X
Poa pratensis	Commercial		X	X
Secale montanum	Turkey PI 274912		X*	
Secale montanum	Pullman PI Station		X	
Forbs				
Achillea millefolium	Reynolds Creek			X
Coronilla varia	Nebraska (Pingitt)			X
Coronilla varia	Commercial (Emerald)			X
Eriogonum umbellatum	Grimes Creek			X
Eriogonum umbellatum	Shaffer Butte			X
Linum lewisii	Appar		X	
Lupinus Spp.	South of Twin Falls			X
Lupinus sericeus	Cedar Mountain, Utah			X
Medicago sativa	Brookinas, South Dakota		X	
Medicago sativa	Idaho (Rhizoma)		X	
Solidago gigantea	Reynolds Creek			X
Shrubs				
Amelanchier alnifolia	Bonneville County, Idaho			X

1/ Plants listed with an (x) have performed well at a planting site.

2/ Plants listed with an (*) are the most promising species.

and some rabbits. In 1978 and 1979, grasshoppers made considerable use of most plants, including the native species of bluebunch and western wheatgrass. Insect use varied among species and the hybrid species received as much damage as most others.

The dryland form of orchardgrass, recently released as "Paiute" initially established, but weakened and died in 1978. Other strains of orchardgrass responsed similarly.

Nancy Gulch Study Site

Both the Nancy Gulch and Reynolds Mountain sites are located in areas that receive more moisture than at the Flats site. A greater number of species occur at both these upper areas, than at the Flats study plots (Table 5.3). To a certain extent, similar plants have survived and performed well at both of these sites. Nearly all of the grasses planted at both upper locations matured early, and have persisted through years of abnormally low moisture.

"Nordan" crested wheatgrass, "Luna" pubescent wheatgrass, "Lincoln" smooth brome, "Paiute" orchardgrass, and an introduction of mountain rye, Secale montanum, are all well adapted to the Nancy Gulch site. In addition, all collections of intermediate wheatgrass performed well. Both Festuca ovina duriuscula "Doran" (hard sheep fescue) and Festuca ovina sulcata are well adapted to this site. Sulcata sheep fescue is more erect, produces more seed stocks, and drys earlier in the summer than does hard sheep fescue. The herbage produced by hard sheep fescue appears to be more useful as a forage than that of Sulcata. The plants not only provide more green succulent herbage, but form a greater amount of leaves.

The hybrid of crested and fairway wheatgrass is productive and appears well suited to conditions at the Nancy Gulch site. In 1981, the hybrid produced more forage than any of the other seeded grasses.

In addition to the grasses, two forbs--Lewis flax, "Appar", and two strains of alfalfa have performed very well. All are vigorous, productive, and have received considerable use by wildlife. Seedlings of Lewis flax have spread from the original seeded plot. The alfalfa accessions have remained productive even under heavy use by wildlife.

Antelope bitterbrush seedlings have responded erratically. Yet, plants that have been able to establish amid heavy grass competition, are now beginning to attain a reasonable size. Shrub seedlings are sensitive to competition from annual and perennial grasses for one to four years after seeding. Once these plants become 12-15 inches in size, they are able to compete with the herbs.

A number of useful herbs can be established in the sagebrush types that dominate the Nancy area. If competition is reduced for one to three years, various shrubs can also be established and maintained.

Reynolds Mountain Study Site

Although the Reynolds Mountain study area is a more productive site than the other two, establishment and maintenance of seeded species is not always easily attained. Rodents, including gophers, selectively use certain grasses and forbs, and when these species are planted in small amounts as in experimental plots, the plants are destroyed by grazing and burrowing.

Plots of smooth brome and intermediate wheatgrass are well suited to this site. Other grasses, including orchardgrass, Canada bluegrass, and meadow foxtail, are also well adapted and productive. The sod forming

grasses are better able to withstand destructive digging by gophers, than are bunchgrasses.

A number of forbs are also adapted to the area, although some are not able to survive heavy rodent use. Alfalfa is perhaps the most productive broadleaf forb, yet gophers continue to forage on the roots, causing die back. Only rhizomatus types of alfalfa should be planted in these gopher dominated sites.

HERBAGE RESPONSE AFTER MECHANICAL AND HERBICIDE TREATMENT OF BIG SAGEBRUSH

This study was conducted from 1971 through 1975 at the Nancy Gulch, Upper Sheep Creek (dense) and Reynolds Mountain (dense) sites, and at the Whiskey Hill site from 1972 through 1975 (See Figure 5.1 and Table 5.2). Treatments at the first three sites were: 1) Mechanical (all sagebrush plants grubbed out); spraying with 2, 4, 5-T at Upper Sheep Creek and with 2, 4-D at the other two sites; 3) ungrazed (grazing excluded); and 4) grazing. The mechanical treatment was not included at the Whiskey Hill site. The same harvesting procedures were used in this study as was used in the first section of this report (see page 5-3 for more detail about plot design, harvesting procedures, etc).

Results from this study showed that the average annual herbage yield from each of the four treatments was about the same at each site but that grasses made up a higher percent of the total yield in the mechanical and sprayed treatments. The total average annual site yield was: 694, 979, 1577, and 1189 lb/acre for the Nancy Gulch, Whiskey Hill, Upper Sheep Creek (dense), and Reynolds Mountain (dense) sites, respectively. The average non-sage yield accounted for: 84, 85, 92, and 96 percent of the total on the mechanical and sprayed treatments at the Nancy Gulch, Whiskey Hill, Upper Sheep Creek (dense) and Reynolds Mountain (dense) sites, respectively; whereas, the average non-sage yield accounted for only 53, 52, 52, and 26 percent of the total yield on the untreated and grazed sites. See Schumaker and Hanson (1977) for a detailed analysis of this study.

REYNOLDS CREEK SOILS

Introduction

Eight soil associations have been mapped and described on the watershed (Stephenson 1977). Additional information on the watershed soils at representative sites was obtained through cooperative work with the SCS National Soils Lab in 1980-82.

The associations are described below. Tables of detailed data for representative sites within the associations, obtained from the recent cooperative work with the SCS, may be found in Volume III, Section E.2. During this latter work, the soils for each site were redescribed according to the 1975 Soil Taxonomy. Consequently, the most recent descriptions may not agree in detail with the earlier soil association descriptions which were described in 1961-64. An update survey of the Reynolds Creek Watershed soils is presently underway to meet the new Taxonomy and classification system.

Soil Associations

The eight soil associations are described below and given on the Soil Association Map, Figure 5.3.

Takeuchi-Kanlee-Ola Soil Association

This soil association occupies about 12 percent of the watershed and is principally the high mountain uplands in the southwestern and southeastern part. The principal area extends about 6 miles south from the Whiskey Hill road. A smaller area is in the extreme southeastern part on Slack Mountain. The association is dominantly represented by dark or very dark soils in rolling to steep uplands. The soils formed in material weathered from granitic rocks. The vegetation consists of bluebunch wheatgrass, Idaho fescue, big sagebrush, mountain mahogany, rabbitbrush, bitterbrush, snowberry lupine, yarrow, Indian paintbrush, larkspur and wild mustard.

This soil association consists of about 60 percent Takeuchi soils, 25 percent Kanlee soils, and about 10 percent Ola soils. Takeuchi soils occupy the lower, warmer and drier areas, particularly the south slopes; Kanlee soils occupy the ridges; and Ola soils are on steep northerly slopes. Takeuchi soils typically have dark grayish brown coarse sandy loam A1 horizons and coarse sandy loam B horizons. The Kanlee soils typically have very dark grayish brown coarse sandy loam A1 horizons and slightly gravelly sandy clay loam B2t horizons. Ola soils typically have thick very dark grayish brown coarse sandy loam A1 horizons and bedrock between depths of 20 and 40 inches.

Harmehl-Gabica-Demast Soil Assóciation

This association occupies about 25 percent of the watershed in the extreme southwest and northwest parts and consists of high, undulating to steep uplands and associated erosion surfaces. Basalt is the principal rock type. Virtually all of the soils are free of calcium carbonate and are at least slightly acid.

The vegetation consists of big sagebrush, snowberry, bluebunch wheatgrass, Idaho fescue, mountain bromegrass, lupine, Sandberg bluegrass, yarrow, cheatgrass, junegrass, stipa, bitterbrush, giant wildrye, mules ear and some serviceberry, elderberry, wild buckwheat, wild rose, rabbitbrush, arrowleaf balsam-root, mint, aspen, and scattered Douglas-fir.

The Harmehl and Gabica soils represent about one-third each of this association; the Demast soils, about 10 percent; and the Nettleton and Gemid soils, about 24 percent. The Harmehl soils occupy ridges and less steep slopes at the higher elevations. The Gabica soils have mostly south slopes and the Demast soils occupy steep northerly slopes. The Gemid soils are mostly at the lower elevations of this association. The Nettleton soils are in alluvial and colluvial footslopes.

The Harmehl soils have dark grayish brown and dark brown loam A1 horizons, brown gravelly and cobbly clay loam B2t horizons and are underlain by basalt at a depth between 20 and 40 inches. Gabica soils typically have dark grayish brown cobbly and gravelly loam A1 horizons and very gravelly clay loam B21t horizons, and are underlain by basalt at depths between 10 and 20 inches. Demast soils have thick, very dark grayish brown gravelly loam A1 horizons, gravelly clay loam B2t horizons and are underlain by basalt at a depth below 40 inches. Gemid soils have dark gray loam and clay loam A1 horizons, clay B22t horizons and basalt

Figure 5.3.--Soil associations map. Numbers (i.e., 5) refer to site locations.

bedrock between 20 and 40 inches below the surface. The Nettleton soils typically have dark grayish brown loam A1 horizons, light-colored A2 horizons and slightly gravelly clay B22t horizons. Bedrock is below a depth of 40 inches.

Searla-Bullrey Soil Association

This association occupies about 4 percent of the watershed and is in the Black Mountain, Johnson Draw Basin, and Reynolds Mountain areas. It is represented by dark soils in high, dissected, hilly to rolling uplands and alluvial deposits. The soils developed principally in materials weathered from rhyolitic or related rocks. The vegetation consists of big sagebrush, bitterbrush, rabbitbrush, snowberry, low sagebrush, bluebunch wheatgrass, Idaho fescue, Sandberg bluegrass, squirreltail grass, cheatgrass and other associated plants.

The Searla soils represent about 70 percent and the Bullrey soils about 20 percent of this association. The Searla soils typically have grayish brown and dark grayish brown, very gravelly loam A1 horizons, and very channery clay loam B22t horizons. Bedrock does not occur within 40 inches of the surface. Bullrey soils typically have thick, dark grayish brown gravelly loam A1 horizons, gravelly loam Bt horizons, and do not occur within 40 inches of the surface.

Glasgow-Lassen Soil Association

This association occupies about 3 percent of the watershed. It is located in the north-central part of the watershed in gently sloping to steep, dissected low uplands, pediments or alluvial deposits, which are underlain by light colored siltstone, tuff or consolidated lacustrine sediments. The vegetation consists of big sagebrush, bitterbrush, rabbitbrush, cheatgrass, Sandberg bluegrass, squirreltail, and some bluebunch wheatgrass and associated plants.

The Glasgow soils represent about 90 percent and the Lassen soils about 10 percent of this association. The Glasgow soils typically have light brownish gray loam A2 horizons and heavy clay loam B22t horizons. Lassen soils typically have dark grayish brown silty clay surface and subsoils.

Nannyton-Larimer-Ackmen, Dark-Gray Variant Soil Association

This association occupies about 12 percent of the watershed. It is located in the lower north-central part of the watershed and is represented by light and dark soils in level to moderately steep alluvial deposits and bottom lands. The vegetation consists of big sagebrush, Sandberg bluegrass, cheatgrass, bluebunch wheatgrass, spiny horsebrush, squirreltail grass, wild mustard, greasewood, shadscale, budsage, and some moss under the brush.

The Nannyton soils represent about 50 percent; the Larimer soils 30 percent; the Ackmen, dark gray variant, 12 percent; and other minor soils, the remainder of the association. Nannyton soils have light brownish gray gravelly loam A2 horizons, pale brown gravelly clay loam B2t horizons and a strong accumulation of lime below a depth of 10 to 16 inches. They are formed in alluvium weathered from mixed materials. Larimer soils typically have light brownish gray gravelly loam A2 horizons, slightly gravelly clay loam B2t horizons, and a distinct accumulation of lime below a depth of 6 to 18 inches. They are formed in alluvium mainly weathered from basaltic materials. The Ackmen dark gray variant soils typically have thick dark gray loam Ap horizons and stratified subsurface horizons,

and are developed bottom land alluvium weathered mostly from granitic rocks.

Bakeoven-Reywat-Babbington Soil Association

This association occupies about 35 percent of the watershed and occurs in the northwestern, northeastern and east-central parts. The soils are dominantly dark and have developed in materials weathered from basalt or in deep colluvium and alluvium weathered mostly from basaltic rocks. The vegetation consists of big sagebrush, rabbitbrush, bitterbrush, Sandberg bluegrass, squirreltail grass, cheatgrass, bluebunch wheatgrass and other forbs and grasses.

The Bakeoven soils represent about 30 percent; the Reywat soils, 25 percent; the Babbingotn soils, 20 percent; the Ruclick soils, 15 percent; and the Newell, Gemson, Lickskillet and Squaw soils, the remainder of the association. The Bakeoven, Reywat, Ruclick and Lickskillet soils are in the undulating to steep uplands. The Babbington, Gemson, Newell and Squaw soils occupy alluvial deposits, pediments, coluvial footslopes and other slopes in the uplands, and are developed in colluvium or local alluvium. In general, the Babbington soils are in the lower or drier areas and the Gemson, Newell and Squaw soils are in higher, more moist areas.

Typically, Bakeoven soils have brown very gravelly loam A1 horizons and brown very gravelly loam B horizons. Basalt is within 10 inches of the surface. Reywat soils typically have grayish brown stony loam A1 horizons and brown sandy clay loam B22t horizons, containing more than 35 percent coarse fragments. Basalt is at a depth between 10 and 20 inches and some calcium carbonate is just above the bedrock or in cracks in the bedrock. Babbington soils have grayish brown stony loam A1 horizons, brown clay loam B22t horizons, and a moderate accumulation of lime below a depth of 15 to 22 inches. Ruclick soils have grayish-brown, very-stony gravelly loam A11 horizons and brown clay B22t horizons, containing more than 35 percent coarse fragments. Basalt bedrock is at a depth between 20 and 40 inches.

Farrot-Castlevale-Brownlee Soil Association

This association occupies about 6 percent of the watershed. It is located in the northern and west-central part of the watershed in rolling to steep disected uplands, pediment surfaces, and alluvial deposits. The soils range from light to dark and developed principally in residuum weathered from granite, arkosic rocks or related bedrock or in colluvium and alluvium, derived from such materials. The vegetation consists chiefly of big sagebrush, rabbitbrush, bluebunch wheatgrass, cheatgrass, Sandberg bluegrass, squirreltail grass and associated plants.

The Farrot and Castlevale soils represent about 35 percent each; the Brownlee soils, 15 percent; Haw, Lolalita, and the other soils, the remainder of the association. In general, the Farrot soils occupy ridges and southerly slopes in the more moist part of this association. The Brownlee soils occupy mainly northerly slopes at the higher elevations. The Castlevale soils are in the drier areas. The Haw and Lolalita soils occupy alluvial deposits, pediments and coluvial slopes. Bedrock is below a depth of 40 inches.

Farrot soils have dark grayish brown slightly gravelly coarse sand loam A1 horizons, slightly gravelly coarse sandy clay loam B22t horizons and a weak lime accumulation. Bedrock is at a depth ranging from 20 to 40

inches. The Brownlee soils resemble the Farrot soils but typically have dark-gray, A1 horizons, have no calcium carbonate and are more acid. The Castlevale soils typically have brown, extremely stony, fine gravelly coarse sandy loam A1 horizons, gravelly light coarse sandy loam A1 horizons, gravelly light coarse sandy clay loam B2t horizons and lime accumulations. Bedrock is at a depth between 10 and 20 inches.

Hoot-Nannyton Soil Association

This association occupies about 2 percent of the watershed. It consists primarily of light colored soils in hilly to steep uplands, slightly dissected pediment surfaces, and alluvial and colluvial deposits in the northeastern part of the watershed. The soils developed in residuum weathered from rhyolite bedrock and in colluvium and alluvium derived from such materials. The vegetation is chiefly shadscale, spiny hopsage, budsage, cheatgrass, spiny horsebrush, squirreltail grass and wild mustard.

The Hoot soils are predominant in this association. Typically, Hoot soils have light brownish gray, very-stony, very-gravelly loam A horizons and very gravelly loam B2tca horizons between fractures in bedrock. Bedrock is within 20 inches of the surface. The Nannyton soils have light brownish gray gravelly loam A2 surface horizons, pale brown gravelly clay loam B2t horizons, strong accumulations of powdery lime below a depth of 10 to 16 inches, and underlying stratified sediments.

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Chapter 6

RESOURCE MONITORING

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Chapter 6

RESOURCE MONITORING

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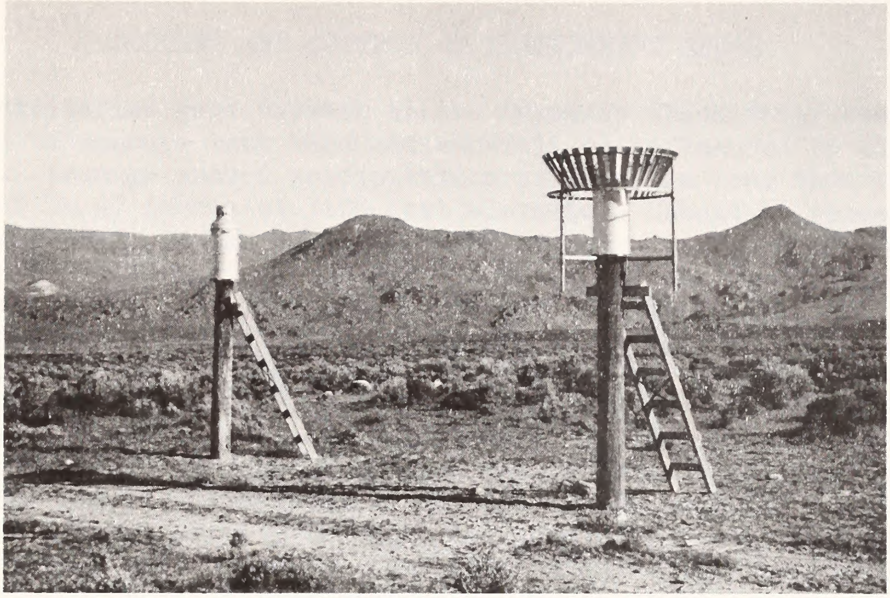
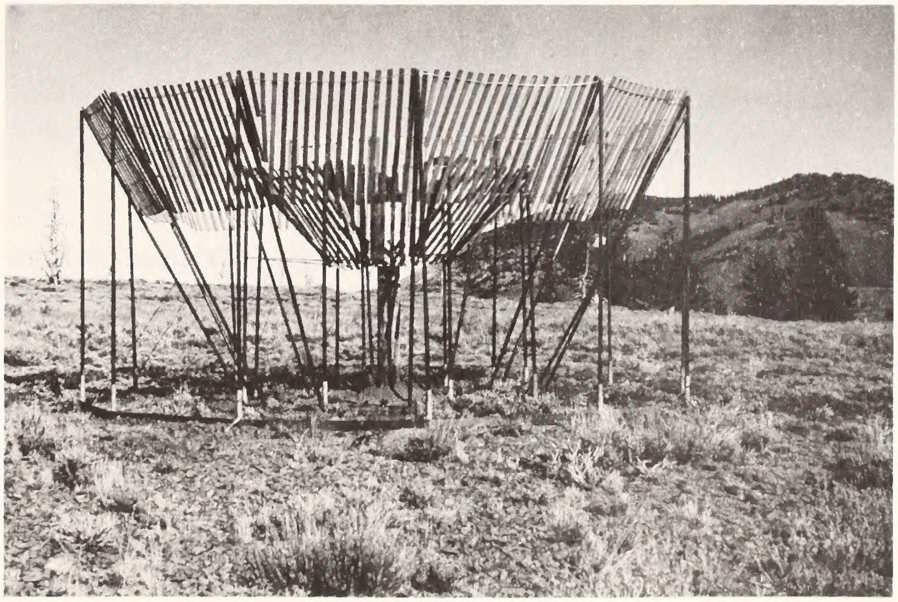


Typical Dual Precipitation Gage System



Typical Wyoming Shield Precipitation Gage System

SOURCES AND CONTROL OF MEASUREMENT ERROR

The precipitation gage network on the Reynolds Creek Watershed was established to measure both rain and snowfall as influenced by elevation and season. Average annual precipitation varies from less than 10 inches at 3885 foot to 43 inches at 7100 foot elevation. About 56 percent of the annual precipitation falls during November through April at the lower elevations and 76 percent at the high elevation sites, which indicates that a considerable portion of the annual precipitation falls as snow; thus compounding the number of measurement problems.

The original gage network, established in 1960-61, consisted of 83 unshielded gages (Hamon 1971; Hanson et al. 1980). This network was converted to 46 dual-gage sites during 1967-68, because a considerable portion of the annual precipitation was snow and the unshielded gages were not measuring snowfall adequately. The network was further reduced during 1976-77, to 19 sites after a thorough analysis of records to determine which gage sites best represented different areas of the watershed.

The dual-gage installations consist of one shielded and one unshielded National Weather Service (NWS) standard weighing-type recording gage (see photograph, page 6-2). The gages were set 20 feet apart with orifices at 10 feet. The shield used was similar to the modified Alter shield with a diameter of 46 inches, but with the baffles individually constrained at an angle of 30° from the vertical (Hamon 1972, 1973). At most sites, the unshielded gage has a 24-hour per revolution time-scale and the shielded gage has a 192-hour per revolution time-scale. The continuous precipitation record for the dual-gage sites is computed using the following equation:

$$\ln \frac{U}{A} = B \ln \frac{U}{S} \qquad [6.1]$$

where, ln denotes natural logarithm, A is the computed precipitation, U is the unshielded precipitation, S is the shielded precipitation, and B is a coefficient, (Hamon 1972, 1973; and Hanson et al. 1979). We are using a value of 1.8 for B at the present time (Hamon 1972); and studies are underway to determine how well this value represents all of the climatic conditions on the watershed.

The ratio U/S is computed on a storm basis and not at each breakpoint. The continuous breakpoint record is digitized from the 24-hour revolution chart, via a digitizing system and stored directly on a computer disk, and then converted to breakpoint values of A by using the U/S ratio obtained for each storm.

Most of the gage sites are serviced weekly, because experience has shown that this is the best way to insure a consistent, high quality record. Electric clocks (Belfort Instrument Company) were installed at all sites in 1979 (Morris and Hanson 1982). Since then, some sites are serviced every two weeks with very limited loss of data. Gages are also serviced after major storms, along with the regular weekly service

schedule. All gages are cleaned and calibrated each fall (Brakensiek et al. 1979).

The major problems with measuring rain and snowfall are the amount of time and the personnel required to obtain accurate data. The service time for most remote sites has been cut by reducing the number of sites and installing the new Belfort electric clocks, which have operated very well. Problems in obtaining consistent snow water content data have been alleviated through personnel training. Other problems encountered and what has been done to correct them, or at least reduce these problems, are listed in Table 6.1.

Precipitation Measurement

Wyoming Shield Precipitation Measurement System

A study was initiated in 1977 to determine how well the precipitation catch compared between Wyoming shield gages and the dual-gage system. Data were obtained at four sites (076X59, 127X07, 167X07, and 176X14, (see Chapter 1, Figure 1.1) for varying lengths of time during the study. The Wyoming shield was used as a check of the dual-gage system because Brewer (1973), Rechard (1975), and Rechard and Larson (1971) indicated that Wyoming shield gage catch was very close to true precipitation fall even when the precipitation was snow.

The Wyoming shield gage system consists of two concentric shields mounted around a NWS standard recording gage, as shown in the photograph on page 6-2. The gage orifice is 7.5 feet above ground, which is the same height as the top of the inner shield. The top of the outer shield is 9.5 feet above ground. The diameter of the top of the inner shield is ten feet, and the diameter of the top of the outer shield is 20 feet. The inner shield is 45° and the outer shield is 30° from vertical. The shielding is constructed from 4 foot, 50 percent density snow fence.

Precipitation from events of 0.10 inches or more were analyzed. Precipitation events were considered separate when no measurable precipitation fell for more that four hours. Analyses to date indicate that the dual-gage systems and the Wyoming shielded gages recorded the same amount of precipitation for rain and wet snow when the value of B in Equation [6.1] was 1.8. When snowfall was during cold weather (temperatures less than 34° F), the Wyoming shielded gages did not catch as much precipitation as was computed from the dual-gage system. This difference in catch is being investigated at sites on the Reynolds Creek Watershed and by David Sturgis of the Rocky Mountain Forest and Range Experiment Station in Laramie, Wyoming. These studies relating the cold snowfall catch between the dual-gage system and Wyoming shielded gages will not be completed for at least two more snow seasons.

Heated Tipping-Bucket Precipitation Gages

A study was conducted during the winters of 1980-81 and 1981-82 to determine if heated tipping-bucket gage catch was the same as standard weighing and recording gage catch. Heated gages that were shielded the same as the dual-gage system were installed at sites (076X59 and 176X07 for this study (Table 6.2). Analyses of the data from these two sites show that the heated gages recorded about 25 percent less precipitation than the shielded standard weighing and recording gages for events equal to or greater than 0.05 inches (Hanson et al. 1983). These results indicate that heated tipping-bucket gage data do not represent

Table 6.1.--Data quality evaluation.

Description of current stations	Estimate of data quality	Special problems and comments: problem	Special problems and comments: solution
Precipitation:			
Standard weighing and recording gages (Belfort Instrument Company)	Good	Clock stopping	Electric clocks and frequent service
		Snow capping	Painted collector black
		Pen caught under drum in hail storms or snow capping	Placed a small wire under the pen arm
		Dash pots freezing	Used antifreeze in dash pots
Snow courses	Good	Obtaining consistent data	Observer training
		Site selection	Thorough site evaluation
Runoff/Streamflow/Groundwater:			
Drop-box weirs	Excellent	Ice	Installed heaters and enclosures
90° V-notch weirs	Excellent	Ice	Installed heated enclosures
SCOV weir	Fair-poor	Upstream sediment deposits	Mechanical cleaning
Groundwater-recorders	Good-fair	Battery failures, freezing, blowing snow	Improved enclosures
Groundwater-tape measurement	Excellent	Tape error	Technician training

Table 6.1.--Data quality evaluation--Continued.

Description of current stations	Estimate of data quality	Special problems and comments: problem	solution
Sedimentation:			
P.S. 69 automatic pumping samplers	Good	Representative sampling	Drop-box intake
Chickasha automatic pumping sampler	Excellent	Pump failure-coarse sediment	Use for low concentration only
ISCO portable pumping samplers	Good-fair	Battery failures and freezing difficulties	Large batteries, enclosures
Helley-Smith bedload samplers	Unknown	Calibration unknown	Laboratory calibration in progress
Water Quality:			
Chemical concentrations	Good-excellent	Sample variability	Used standard procedures
Bacteriological concentrations	Good	Contamination delayed	Used sterile containers, rapid handling, and refrigeration

Table 6.2.--Comparison between the heated tipping-bucket gages and weighing-recording gages during the winters of 1980-81 and 1981-82.

Gage Site	Measured amounts for events $\geq$ 0.10 mm			
	Heated (in)	Control (in)	Percent[1/]	Number of Events
1	24.80	32.99	75	60
2	4.41	5.75	77	30

[1/] Heated gage recorded amount divided by the weighing-recording gage catch times 100.

precipitation in areas such as Idaho, where a larger portion of annual precipitation is snowfall.

RUNOFF/STREAMFLOW/GROUNDWATER

The need for accurate streamflow data to support complex hydrologic modeling was recognized from the beginning of the project and watersheds were selected where bedrock exposures made construction of precalibrated weirs or flumes feasible.

Hydraulic laboratory modeling to adapt the Walnut Gulch flumes to the Reynolds Creek Watershed outlet station resulted in development and construction of a modified V-notch weir with a capacity of 20,000 ft^3/sec (Bloomsburg and Tinney 1961). Major floods and deposits of coarse sediment upstream from the V-notch weir caused abnormal flow conditions and inaccurate data, which required expensive sediment removal to produce acceptable measurement accuracy. Concern for quality of streamflow data and plans for weirs at additional sites demanded a permanent solution to the problem. Additional hydraulic laboratory modeling soon produced the drop-box weir, which effectively controlled approach conditions and provided accurate streamflow data (Johnson et al. 1966). Drop-box weirs of various sizes have been constructed and operated successfully at 10 Northwest Watershed Research sites since first designed in 1963.

At streamflow measuring sites and plots where sediment deposition is not a problem, standard 90° V-notch weirs and Belfort FW-1 recorders provide excellent records. Parshall flumes have been used in irrigation ditches and produce excellent records, except where upstream sediment deposition causes abnormal approach conditions.

Weirs and flumes are generally equipped with conventional staff gages, stilling wells, floats, and Leopold-Stevens A-35 recorders. However, because of occasional plugging of inlet pipes with sediment at some stations, auxiliary pressure sensors and recorders insure against loss of records during critical floods. Clocks and recorders are cleaned and repaired regularly.

Recording of streamflow during subzero temperatures has been accomplished by completely enclosing and heating small weirs (capacities less than about 250 ft^3/sec). However, for larger weirs electric or infrared gas heaters are used as necessary.

A major effort has been made in site excavation, bedrock grouting, and preparation of the surface for placing concrete or metal cutoff walls to prevent underflow and seepage around the weirs, and to assure total flow measurements. Laboratory calibration tables and equations are verified by volumetric and current meter flow measurements, except flood discharges, which depend entirely upon laboratory calibrations.

Groundwater level measurements and pump tests are made to determine aquifer storage and recharge characteristics in response to hydrologic conditions on sagebrush rangelands and irrigated areas. Springs and wells are sampled periodically to determine chemical constituents of the groundwater flow systems. Water level changes are measured weekly or bi-weekly by tape or continuously by a combination of Keck water sensors and Stevens Type F recorders. About 90 wells have been drilled and observed for various periods to study groundwater chemistry and hydrology.

Original streamflow gaging stations with natural controls were unacceptable on Reynolds Creek because of extreme changes in channel

cross-sections during flood events. Therefore, precalibrated weirs or flumes were installed at all stations (Table 6.1). Generally, few problems have been experienced in obtaining excellent quality streamflow records at weirs during low flow, except during subzero weather. In a few cases, ice buildup at large weirs was too severe for removal by heaters or mechanical means and streamflow was estimated. However, severe icing is usually during baseflow periods and inaccuracy does not adversely influence snowmelt and flood analysis. Heating stilling wells and inlet pipes is of utmost importance to assure rapid response to snowmelt and storm runoff following extreme cold.

During and following flood events, the greatest problem is sediment deposition and scour in the weir approach. The drop-box weirs have solved this difficult problem and pass even large boulders. Also, the drop-box weirs facilitate design of flushing systems to keep stilling wells and intakes free of sediment.

Streamflow recorder malfunctions, failures of clocks and inking systems, and vandalism are continuous problems and justify weekly or more frequent servicing at most stations to assure quality data (Table 6.1). Also, backup recorders and pressure transducers or other auxiliary systems prevent loss of important data.

Groundwater measurements and sampling in small diameter wells are often difficult, especially during periods of rapid recharge. Frequent field checks and instrument maintenance are critical in obtaining quality data. Winter operation of recorders is complicated by blowing snow and battery failures when data are critical.

SEDIMENT CONCENTRATION/TRANSPORT

Hand-operated U.S. DH-48 suspended sediment samplers are used from bridges and weirs, or by wading to obtain depth-integrated sediment concentrations. Sample concentrations are plotted against measured streamflow to determine suspended sediment transport rates and amounts. Results of sediment sampling are also used to determine location of pumping sampler intakes which will represent total stream sediment transport. Because 50-90 percent of annual sediment yield from most study watersheds is produced by a few major runoff events each year, a major goal of the sediment sampling program is to obtain frequent samples at representative sites during flood and snowmelt events (Johnson and Hanson 1976).

Automatic pumping samplers are used at weirs and flumes to determine suspended sediment concentrations and yields under a wide range of conditions. Generally, Chickasha and ISCO pump samplers function well on small watersheds with concentrations less than 2000 mg/l. However, on watersheds greater than 200 acres, where coarse bedload sediment is common, the U.S. PS-69 samplers are more successful. Details of sediment sampler models, design, and operation are discussed by Allen (1981). Pumping samplers with intakes in drop-box weirs provide excellent results from a minimum number of samples.

Since major runoff and sediment movement on the study watersheds sometimes occurs following periods of subzero temperatures, successful pump sampler operation requires heated enclosures and well designed sampler intakes. Also, solar and wind-powered battery chargers are essential for dependable long-term sampler operation during snowmelt

runoff. Overall, considerable equipment and personnel are required to obtain adequate sediment samples with extremes of temperature, a wide range of site conditions, and numerous unexpected instrument problems at remote sites.

Sampling and particle-size analysis of bedload sediments were reported by Johnson and Smith (1978). Bedload samplers of the type designed by Helley and Smith (1971) and tested by Johnson et al. (1977) are used to determine bedload transport-streamflow relationships. Complete calibration and testing of this type of bedload sampler is still in progress at the St. Anthony Falls Interagency Sedimentation Laboratory, Minneapolis, Minnesota.

Automatic pumping samplers at remote sites with difficult access during storms and floods present numerous problems in obtaining samples representative of widely varying flow conditions. Most frequently experienced failures are electronic switches and controls, mechanical malfunctions of pumps, plumbing leaks, advancing mechanisms, and battery power systems (Table 6.1). Availability of an experienced electronic technician is most important in keeping samplers operating properly.

Representativeness of individual samples is ever a problem, which demands all the duplicate sampling feasible. Thus, concurrent hand-operated sampling and pump sampling is necessary during major events. Often this requires working during heavy rain, cold, and darkness. The need for well trained technicians cannot be overemphasized.

WATER QUALITY

Chemical Concentrations

Concentration of the chemical constituents associated with streamflow have been determined for both the dissolved and adsorbed states. Samples have been obtained by U.S. DH-48 hand samplers and from automatic pumping samplers, which are used for suspended sediment determination at weirs and flumes. Samples are usually taken at regular schedules during low flow (baseflow conditions) at weirs, flumes, and other stream segments where flows are measured. More frequent samples have also been taken at weirs and flumes during peak flow from rainstorm and snowmelt events.

Samples are immediately taken to the lab and analyzed for standard ionic and nonionic concentrations. Laboratory equipment for determining concentrations include standard spectrophotometer for measuring light transmittance, atomic adsorption spectrophotometer, ionalyzers, and other standard wet chemistry equipment. Every effort is made to either analyze samples immediately, or fix, and/or freeze them because of the potential for rapid deterioration of some chemical elements.

Bacterial Concentrations

Samples for bacterial analyses of rangeland streams are taken in sterile bottles by hand, within the top 10 cm of the water surface. Because of chances of contamination, automatic samplers are not used for bacteria tests. Depth integrating samples are seldom used because of similar contamination possibilities. Sample contamination is a constant threat and must be recognized and prevented.

Lateral sampling tests within the top 10 cm have been done at most sites to determine sample variability. All samples are incubated within 12 hours.

The Membrane Filter (MF) method is used for all bacteria (total coliform, fecal coliform, and fecal strep.) analyses of waters with low suspended solids. When the suspended solid concentrations are such that individual colony enumeration is difficult by the MF method, the multiple-tube fermentation procedure is followed with results reported as a Most Probable Number (MPN) index. The index number is not a direct colony count and less precise than the MF method. The methods used, therefore, will vary with the particular study, depending primarily on whether suspended solids are involved (Stephenson and Street 1978; Rychert and Stephenson 1981; and Stephenson and Rychert 1982).

Chemical Analyses

Interpretation of chemical concentrations of streamflow on watershed basins is difficult because of great variability in several factors: 1) natural background conditions caused by soil and geologic differences; 2) management practices; and 3) seasonal and weather changes. To accurately determine the chemical concentrations (in both the dissolved and adsorbed states), and to understand inter-relationships, these variables must be a part of the research. Quality results depend on accurate precipitation and streamflow measurement and accounting for management changes, irrigation return flows, grazing practices, herbicide and pesticide application, and soil and geologic variabilities. Often the number of samples analyzed is not commensurate with our needs because of the high cost of analytical determinations or the lack of help necessary to complete the assays. Strict adherance to standard methods and procedures minimizes sample variability.

Bacterial Analyses

Because of low background concentration of most chemical constituents and the absence of applied herbicides, pesticides, and fertilizers at our research sites, we have concentrated on bacterial indicators to denote changes in management practices, irrigation return flows, and streamflow variations. Generally, the cost per sample of bacterial analyses is considerably less than chemical analyses.

Greatest problems are contamination and communication. Sample contamination with foreign microbes (microorganisms foreign to the sample site) is difficult to prevent, and usually necessitates visiting sites during storm flows and changes in management (moving cattle from one study basin to another, or irrigation runoff changes). The use of automatic samplers is not recommended unless sterile conditions can be assured.

Communication problems arise because we do not have full control or knowledge of management changes. It is often difficult to obtain accurate cattle numbers and dates when cattle are moved from one grazing allotment to another.

VEGETATION

Herbage yield and plant cover have been the vegetation parameters of concern in the Reynolds Creek Watershed hydrologic studies. In 1982, phenological observations were begun on a few key species. This section of the report will discuss the sources and control of measurement error of these vegetation parameters based on our Reynolds Creek study experiences.

There are several methods used to measure herbage yield on rangelands. The inherent high variable of range vegetation necessitates large numbers of clipping plots to obtain accurate yield estimates. These are expensive and time-consuming, and are often unfeasible within existing time and money constraints. A double sampling technique was used in the Reynolds Creek study to help reduce time and cost without sacrificing sample numbers. This method combines visual weight estimates with actual clipping and weighing of plant material. Yields from a portion of the sampling units are both visually estimated and clipped and weighed. The remaining portion of the sample plots are visually estimated. Descriptions of this method can be found in Wilm et al. (1944) and U.S. Department of Interior 1979. These references should be studied carefully before attempting to use their double-sampling method. Weight adjustment on these plots can be made, if necessary, based on the information obtained from those plots that were both estimated and clipped and weighed.

From our experience, the main sources of error in application of the double-sampling method was in training new people each spring to follow very carefully the procedures that were used the previous year. This problem can only be overcome by having the same people sample each year of a study. This may be possible over the course of a short study, but almost impossible if a study extends over a considerable number of years.

The procedures outlined in BLM guides are adequate for training personnel to do field surveys. The BLM form shown in the guide is also adequate for recording field information.

Cover

Plant cover is a vegetation parameter that is widely used to describe ecological and hydrological conditions of rangelands. It is a complex parameter in that there are many types of cover and many ways to determine it. In the Reynolds Creek Study, our main concern was in describing or quantifying cover as it affects runoff and erosion. Measurements included foliar cover, canopy cover, and ground cover, which included litter (persistent and non-persistent), basal plant cover, and rocks. All plant cover estimates were made by a point-quadrat method.

To compare three point-quadrat methods of measuring cover, a study was conducted on the Reynolds Creek Watershed during 1981 and 1982. A major problem with cover measurements is a lack of compatability among methods and among individuals using the same method. The methods compared included the wheel-point (Tidmarsh and Havenga 1915; and von Broembsen 1965), step-point (Evans and Love 1957; and U.S. Department of Interior 1979), and vertical point-frame (Goodall 1952; National Academy of Sciences 1962; and Hutchings and Pase 1963). In 1981, cover was measured at the Flats, Nancy Gulch, and Whiskey Hill study sites and in 1982, at the Nancy Gulch and Lower Sheep Creek sites (Table 6.3). All cover measurements were made by one individual in 1981 and a different

Table 6.3.--Comparison of cover[1/] measurements made by three different methods and two different operators (1981 and 1982).

Site	Method	First hit cover (%)					
		Grass	Forbs	Shrubs	Litter	Rock	Bare ground
Flats (1981)	Step-point	60[a] [2/]	7[a]	10[a]	2[a]	2[a]	19[a]
	wheel-point	60[a]	7[a]	11[a]	3[a]	1[a]	18[a]
	point-frame	37[b]	5[a]	7[a]	16[b]	5[b]	30[b]
Nancy Gulch (1981)	step-point	35[a]	8[a]	13[a]	5[a]	4[a]	35[a]
	wheel-point	35[a]	10[a]	16[a]	6[a]	2[a]	31[a]
	point-frame	13[b]	13[b]	16[a]	13[b]	8[b]	37[a]
Whiskey Hill (1981)	step-point	53[a]	7[a]	29[a]	4[a]	1[a]	6[a]
	wheel-point	46[b]	8[a]	36[b]	4[a]	1[a]	5[a]
	point-frame	31[c]	9[a]	25[c]	25[b]	1[a]	9[b]
Nancy Gulch (1982)	wheel-point	34[a]	9[a]	11[a]	26[a]	9[a]	11[a]
	point-frame	13[b]	21[b]	7[b]	27[a]	10[a]	22[b]
Lower Sheep (1982)	wheel-point	28[a]	11[a]	27[a]	25[a]	6[a]	3[a]
	point-frame	9[b]	16[b]	23[b]	26[a]	11[b]	15[b]

1/ Percent cover is based on 1000 points in 1981 and 2500 points in 1982.

2/ Cover percentages within site and within class followed by the same superscript are not significantly different; (P = .05).

individual in 1982. The wheel points were two feet from point to point. A pin guided by a notch in the boot was used in the step-point method. Plant hits with the wheel-point and step-point methods were recorded when any part of the pin hit a plant part. The point-frame was a 10-point frame with the pins 2.5 inches apart and sharpened to a fine point on the tip. Only hits on the point of the pin were recorded for the point-frame method. For the three methods, hits were recorded from the ground up with a possibility of four hits per pin. For example, the first recorded hit (ground level) would be litter, rock, basal plant cover, or bare ground. Only rock .08 inches or more in diameter was counted. Moving up the pin, subsequent hits were recorded. Only the first three above-ground hits were recorded, and if the same species were hit more than once per pin, only the first above-ground hit was recorded. In practice, the wheel-point and step-point pins were in place before the hits were observed; for the point-frame, the hits were observed as the pin was moved through the frame to ground level, but recorded on the record from the ground up as with the other two methods. The data from this study are shown in Tables 6.3 and 6.4.

The results of this study show that the wheel-point and step-point methods gave essentially the same results for all cover measurements, while the point-frame method usually measured less first hit plant cover and more first hit litter, rock, and bareground. These results would be expected because only tip hits were recorded by the point-frame method and hits on the side of the pins were recorded for the other two methods. The wheel and step-point pins were about 0.19 inches in diameter and represented a significantly larger area than did the pin tips, and consequently had more foliar contacts. On a first hit basis, increasing foliar hits decreases litter, rock, and bareground hits.

In using the point method, the size of the point or what is considered a "hit" is critical. If just the contact of the point of the pin with vegetation is considered a "hit", then, as the area of the point increases the cover, estimates are biased upward. Likewise, if any contact against the pin is considered a "contact", the larger the diamater of the pins, the larger the cover estimate. Also, plant movements due to wind made determination of cover by the point-method difficult. Comparisons of point "hits' with pin "contacts" are generally not valid.

Perhaps the biggest error in using points to measure cover is the inability of different operators to measure the same things and to measure them the same way. What is canopy cover, foliar cover, or ground cover? At what distance above the ground is a "hit" determined to be a ground "hit" or a foliar or canopy "hit"? What is considered bare ground or rock or litter? How are the fine particles of organic debris on the soil surface recorded? These are the questions an operator must answer. A comparison of Nancy Gulch data from 1981 and 1982 shows the effects of different operators using the same methods (Table 6.3). For first hit cover, the 1981 operator recorded lower litter and higher bareground than did the 1982 operator. For ground level (basal) cover (Table 6.4), the 1981 operator recorded both more litter and bareground and less rock than did the 1982 operator.

An important feature of good cover measurement is some very precise definitions of exactly what is being measured and how it is measured; that is, what is considered a "hit". Such writeups should be included with all cover data. In making treatment comparisons, errors can be considerably reduced by using the same operator throughout the study. Training several

Table 6.4.--Basal cover in percent[1/] measured by the step-point, wheel-point, and point-frame methods.

Site	Method	Grasses	Forbs	Shrubs	Litter	Rock	Bare Ground
Flats	step-point	<.05	3^{ab}[2/]	0	41^{a}	4^{a}	50^{a}
(1981)	wheel-point	<.05	7^{b}	0	42^{a}	2^{a}	49^{a}
	point-frame	<.05	3^{a}	<.05	43^{a}	8^{b}	46^{b}
Nancy Gulch	step-point	<.05	18^{a}	0	24^{a}	5^{a}	53^{a}
(1981)	wheel-point	<.05	23^{b}	0	23^{a}	2^{a}	52^{a}
	point-frame	<.05	17^{a}	<.05	29^{b}	9^{b}	45^{b}
Whiskey Hill	step-point	0	1^{a}	0	73^{a}	2^{a}	24^{a}
(1981)	wheel-point	0	1^{a}	0	73^{a}	2^{a}	24^{a}
	point-frame	0	1^{a}	0	79^{b}	2^{a}	18^{b}
Nancy Gulch	wheel-point	1	52^{a}	<.05	<.05	14^{a}	33^{a}
(1982)	point-frame	1	48^{b}	<.05	2	13^{a}	36^{b}
Lower Sheep Creek	wheel-point	<.05	52^{a}	1	<.05	17^{a}	30^{a}
(1982)	point-frame	<.05	47^{b}	1	1	17^{a}	34^{b}
Average	wheel-point	<.05	27	<.05	28	7	38
	point-frame	<.05	23	<.05	31	10	36

1/ Percentage based on 100 point quadrats per vegetation survey method except at Nancy Gulch and Lower Sheep Creek, 1982, where the percentage for the point-frame method was based on 2500 point quadrats.

2/ The average basal cover at each site for the step-point, wheel-point, and point-frame methods with the same superscript letter are not significantly different at the 0.05 probability level.

operators together or training a new operator under the direction of the previous operator helps control measurement errors.

Plant Phenology

Our experience with phenological measurements or observation is very limited. Major problems in making phenological observations are: 1) identifying specific plant growth stages, such as beginning growth, full flower, anthesis, seed soft-dough, seed hard-dough, senescence, etc.; 2) being on site often enough to observe the growth stages as soon as they occur; and 3) locating and marking representative plants without damaging them or altering their environment.

Again, precise descriptions of the phenological stages being observed are critical to minimizing error among observers. Also, observers need to be familiar with the plants--both taxonomy and morphology. Some training is essential to the collection of good phenological data.

SAMPLE SIZE FOR ESTIMATION OF POPULATION STATISTICS

Precipitation

The spatial distribution of precipitation gaging sites is of concern for range management studies. The results reported here are based on the monthly and annual gage sites on Reynolds Creek Watershed. Regression analyses were used to compute correlation coefficients (r) as an indication of the relationship between gage sites 076X59 and 176X07 and each of the other sites with 20-year records, see Figure 1.1 and Table 1.1, Chapter 1. These analyses show that r decreased as distance increased up to about five miles and then became constant for both monthly and annual precipitation. The lowest monthly r-values at both sites at the five-mile distance were for April, May, and July. The July r-value for site 076X59 was 0.68 which was the only value below 0.70. Figure 6.1 illustrates a monthly (January) catch relationship between paired gages. The annual value of r at five miles was 0.75 and 0.70 for sites 076X59 and 176X07, respectively. At both sites, the monthly r-value of 0.90 was at about 2.5 miles distance or greater except for July when it was about 1.5 miles.

The results of the study indicate that if gage sites are not closer than about five miles from each other, monthly and annual information can be estimated from one gage site. These results also indicate that gages would have to be located within about 2.5 miles of each other if a high monthly correlation is require between gages. This, however, may only hold for the Reynolds Creek Watershed, and the monthly and annual relationships between elevation and precipitation would have to be known before only one gage could be used to represent a watershed.

Vegetation

Point data obtained from the Flats and Nettleton sites were used to indicate how many step-points are required to measure basal cover within 10 and 20 percent of the population mean at the 80 and 90 percent confidence levels. As expected, the data in Table 6.5 shows that the number of step-points varies according to the variable being sampled. If

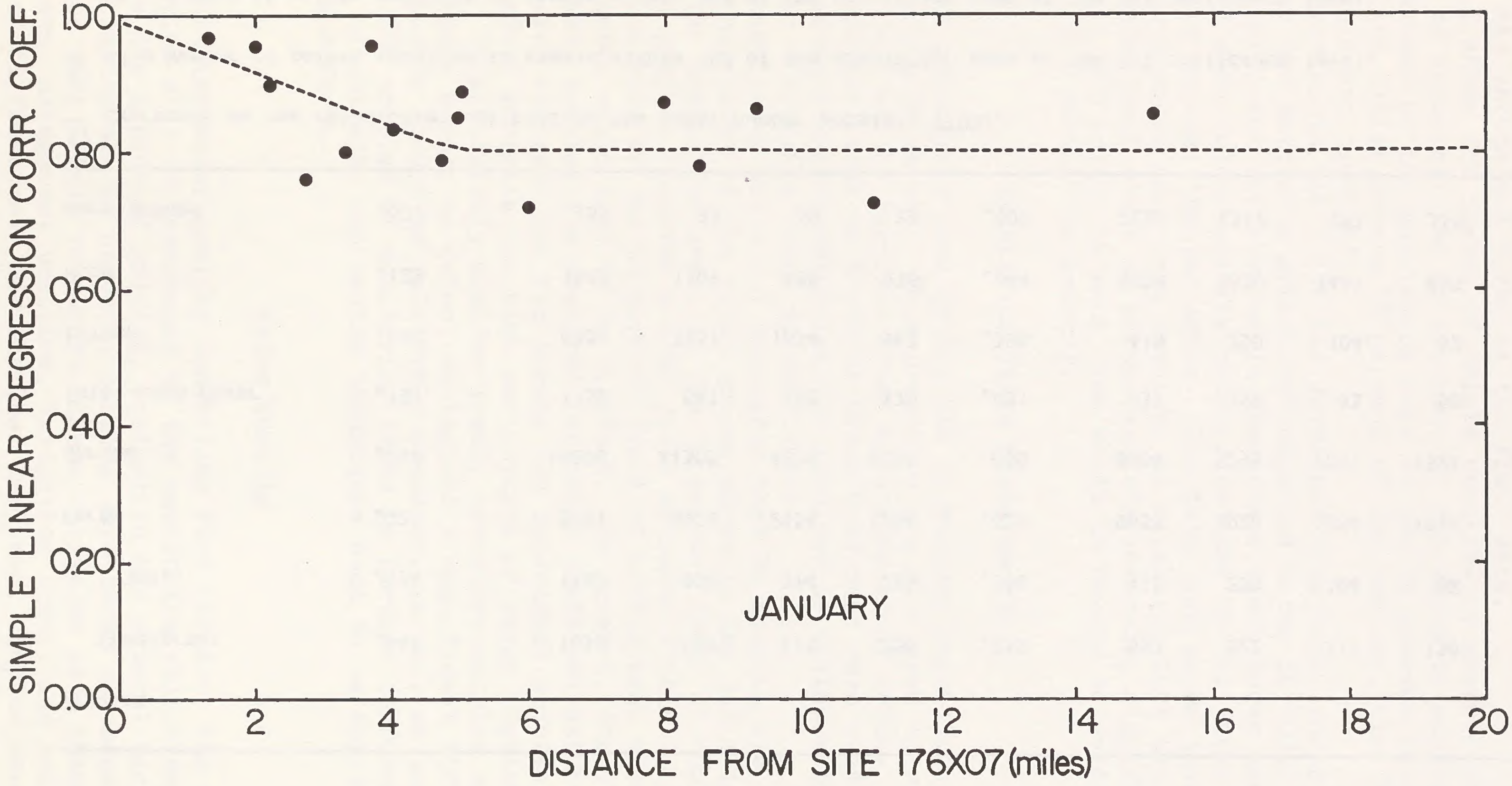


Figure 6.1.--Correlation coefficients for January precipitation for selected gages paired with gage site 176X07.

Table 6.5.--Number of points required to measure basal cover, based on 1975 data from the Flats and Nettleton sites.

Cover Class	Measured Cover [1/]	Flats N1 [2/]	Flats N2	Flats N3	Flats N4	Measured Cover	Nettleton N1	Nettleton N2	Nettleton N3	Nettleton N4
Grasses										
Cheatgrass	.141	1657	997	415	250	.239	867	522	217	130
Total	.154	1497	900	374	225	.396	415	250	104	62
Forbs	.026	9851	5926	2554	1536	.026	9851	5926	2554	1536
Shrubs	.014	18800	11305	4699	2826	.030	8804	5296	2001	1324
Total Live Cover	.194	1132	681	283	170	.451	331	199	83	50
Litter	.040	6535	3931	1634	983	.396	415	250	104	62
Rock	.129	1843	1109	459	276	.044	6028	3626	1487	895
Bare Ground	.637	155	93	39	23	.109	2222	1337	557	335

[1/] Expressed as the ratio of actual hits to the total number possible (700).

[2/] N1 = Number of points required to sample within 10% of the population mean at the 90% confidence level.

N2 = Number of points required to sample within 10% of the population mean at the 80% confidence level.

N3 = Number of points required to sample within 20% of the population mean at the 90% confidence level.

N4 = Number of points required to sample within 20% of the population mean at the 80% confidence level.

the variable sampled covers a high percent of the surface, fewer samples are required than when the variable covers only a small percent of the area, i.e., the shrubs and forbs at the Flats site.

Figure 6.2 shows the number of points required to measure cover at a given level of accuracy. As an example, if one wants to sample litter within 10 percent of the population mean at the 80 percent level of confidence, and litter covers 30 percent of the surface, line N2 shows that 400 points are required.

The information in Table 6.6 was developed from basal cover data obtained from the Nettleton grazed and ungrazed sites in 1975. These data show that significant differences in cheatgrass basal cover could have been measured with relatively few points, because of the large difference in basal cover between the two areas. The data also shows that several thousand points would have been required to establish that the difference measured in the basal cover of shrubs was statistically significant. In general, about 200 points in each area would be needed to detect cover differences of 5 percent or greater.

Vegetation Yield Measurements

One of the procedures used by the BLM to measure vegetation yield is the weight-estimate method. This procedure was also used to measure the vegetation yield on the Reynolds Creek Watershed study areas. Data for two years from two sites on Reynolds Creek Watershed were used to determine how many weight-estimates are required to estimate the mean yield, within a specific level of confidence.

The information in Table 6.7 indicates that 20 samples are required to measure all but three of the yield groups shown in the table to within 20 percent of the population mean, at the 80 percent level of confidence. If the sampling program requires a mean yield estimate within 10 percent of the population mean at the 90 percent level of confidence, about 250 weight-estimates would have to be obtained. In general, the fewest weight-estimate samples are required for total yield estimates, and the greatest number are required for shrubs and individual species.

These results indicate the high variability of range vegetation parameters. To effectively monitor trend, inventory samples should be adequately large enough to detect ecologically significant differences. Indicator species should be relatively abundant, as well as ecologically important. The problem of monitoring trend is further confounded by the variability of climate, and better techniques need to be applied to factor out climatic effects.

Water Quality

When monitoring water quality conditions from streams, the number and size of samples will be determined by the particular objectives. For this study, where the impact of grazing, irrigation and natural background and climatic variables are of concern, samples were taken at channel segments where changes were likely to occur. These variables were changes in cattle numbers, management practice, irrigation input, and soil, geologic, or vegetation differences. For chemical analyses, samples were collected weekly during irrigation season for sites influence by irrigation return flow, and on a storm basis where flood events or snowmelt runoff occurred. For bacterial analyses, samples were collected weekly at outlet of separate

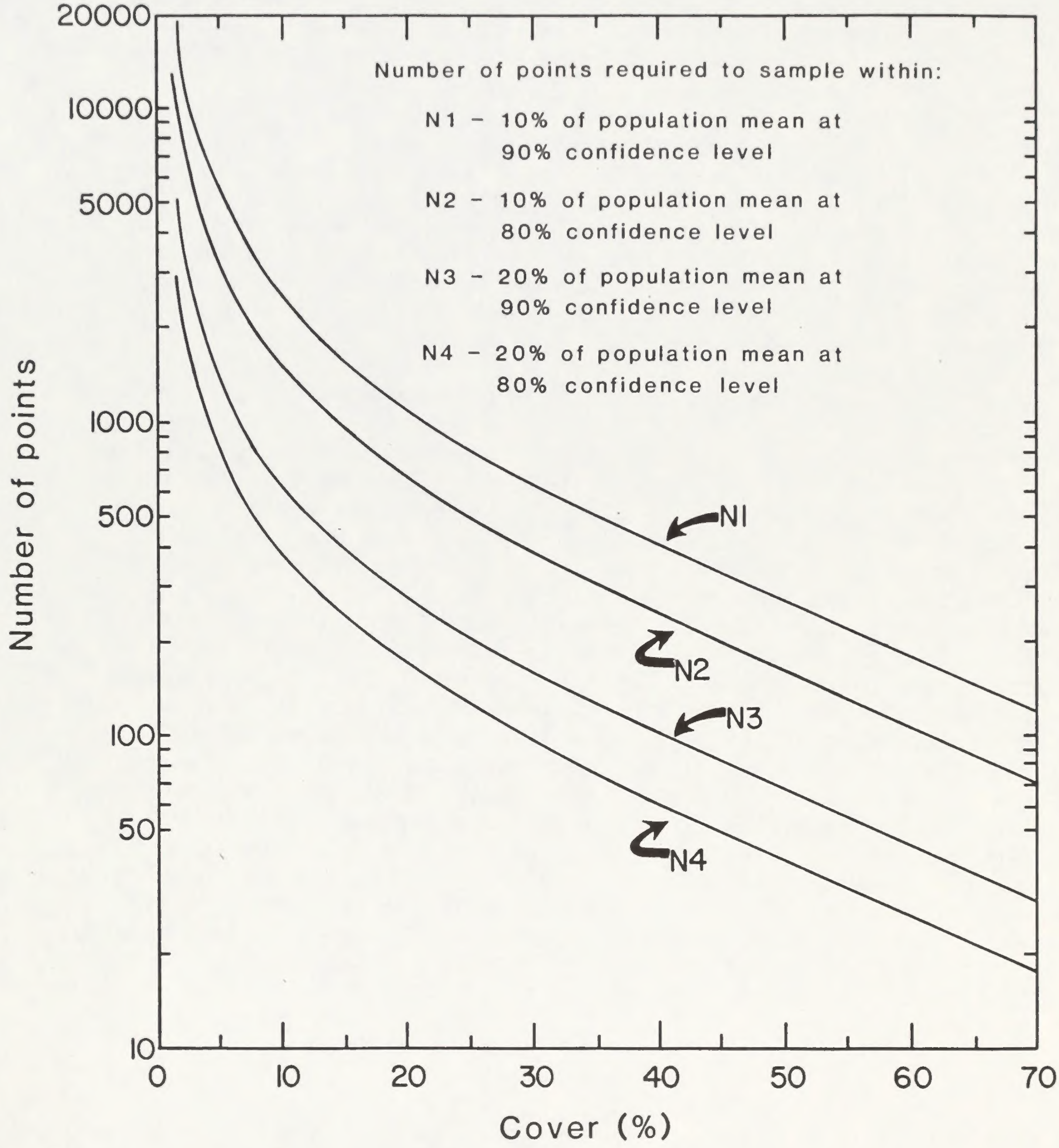


Figure 6.2.--Number of points required to measure cover in a sagebrush-grassland range site on the Reynolds Creek Watershed.

Table 6.6.--Number of points required to determine a statistically significant difference in basal cover between grazed and non-grazed areas on the Nettleton study site, 1975.

Cover Class	Basal cover[1/] No grazing	Basal cover[1/] grazed	Number of points[2/] N1	Number of points[2/] N2
Grasses				
Cheatgrass	.239	.053	19	12
Sandberg bluegrass	.123	.131	9238	5686
Total	.396	.190	26	16
Forbs	.026	.017	1401	858
Shrubs	.030	.026	9068	5441
Total live cover	.451	.233	25	16
Litter	.396	.293	114	70
Rock	.044	.088	171	104
Bare ground	.109	.386	13	8

1/ The ratio of actual hits to total hits possible (700).

2/ N1 = 90% level of confidence.
N2 = 80% level of confidence.

Table 6.7.--Example of the number of weight estimates required to determine the vegetation yield (pounds/acre) at a sampling site.

	Flats, 1977					Flats 1978				
	Measured Mean Yield	Sample Size[1/] N1	N2	N3	N4	Measured Mean Yield	Sample Size n1	n2	n3	n4
Grasses										
Bottlebrush Squirreltail	85	112	28	68	17	297	142	35	86	21
Total	101	72	18	43	11	720	93	23	56	14
Shrubs	162	451	113	272	68	1324	129	32	77	19
Total Yield	263	137	34	82	21	2061	61	15	37	9
	Upper Sheep, 1975					**Upper Sheep, 1974**				
	Measured Mean Yield	Sample Size[1/] N1	N2	N3	N4	Measured Mean Yield	Sample Size N1	N2	N3	N4
Grasses										
Needle-and-thread	21	269	67	161	40	169	134	33	81	20
Total	61	56	14	34	8	169	134	33	81	20
Shrubs	764	164	41	99	25	1188	106	26	64	16
TOTAL YIELD	1267	60	15	36	9	2105	32	8	19	5

[1/] N1 = Number of weight-estimates required to sample within 10% of the population mean at the 90% confidence level.
N2 = Number of weight-estimates required to sample within 10% of the population mean at the 80% confidence level.
N3 = Number of weight-estimates required to sample within 10% of the population mean at the 80% confidence level.
N4 = Number of weight-estimates required to sample within 10% of the population mean at the 80% confidence level.

grazing management pastures during grazing seasons. Special studies were conducted at selected sites to determine concentration variability over time and at various depths at a site, or variability because of differences in runoff. Results of these studies are given in Chapter 4.

METHODOLOGIES FOR DETECTING TREATMENT OR MANAGEMENT EFFECTS ON RANGELAND OUTPUTS

Deterministic Models

Current emphasis in rangeland resource management is the use of point-in-time inventories or measurements to monitor trends or changes in vegetation or soil characteristics. A major problem in monitoring or detecting trend is the confounding effects of climate. It becomes very difficult to discern between treatment or management and climate-induced changes. Often there are treatment-climate interactions.

Deterministic models, such as ERHYM (Wight and Neff 1983), provide a means of quantifying annual climates as they affect plant growth. ERHYM, for example, calculates an annual yield index based on the ratio of actual transpiration to potential transpiration. When water is non-limited for plant growth the yield index is 1.0. Growing seasons can then be compared on the basis of the yield indices. Annual yield data can be normalized to a standard growing season using the yield indices such that much of the climatic effects are removed and the observed differences in yields are due primarily to treatment or management effects.

A similar application of a model to help detect changes in trend is demonstrated in Figure 6.3a using herbage yield as the monitored parameter. Field-measured and model-predicted yields are plotted for a ten-year period. There is a wide variation in field-measured yields which reflect climatic and possibly management effects; no trend is apparent. The variatiom in model-predicted yields reflect only the climatic effects. Thus, the differences in field-measured and model-predicted yields can be used to indicate management induced trend. In the example in Figure 6.3b, the annual ratios of field-measured/model-predicted yields become increasingly less than 1.0, indicating a downward trend that is due to management.

Models, such as SPUR (Simulation of Production and Utilization of Rangelands) (Wight 1983), can be used to predict treatment and management effects through the process of simulation. The model is run for a number of years using a scenario of treatment or management conditions. The scenario can be changed to represent different treatment or management conditions and the model again run for the simulation period. A comparison of model outputs reflect the expected changes due to treatment or management effects.

Statistical Tests

One of the major considerations on rangeland areas is detecting the effects of grazing practices on vegetation characteristics such as yield, species composition, and cover. The presence or absence of a trend for these same quantities is often the main concern. Obviously a sample must be taken, e.g., an entire range area is not clipped, etc. Thus, in the design of a sampling plan or survey, a stage is always reached when the

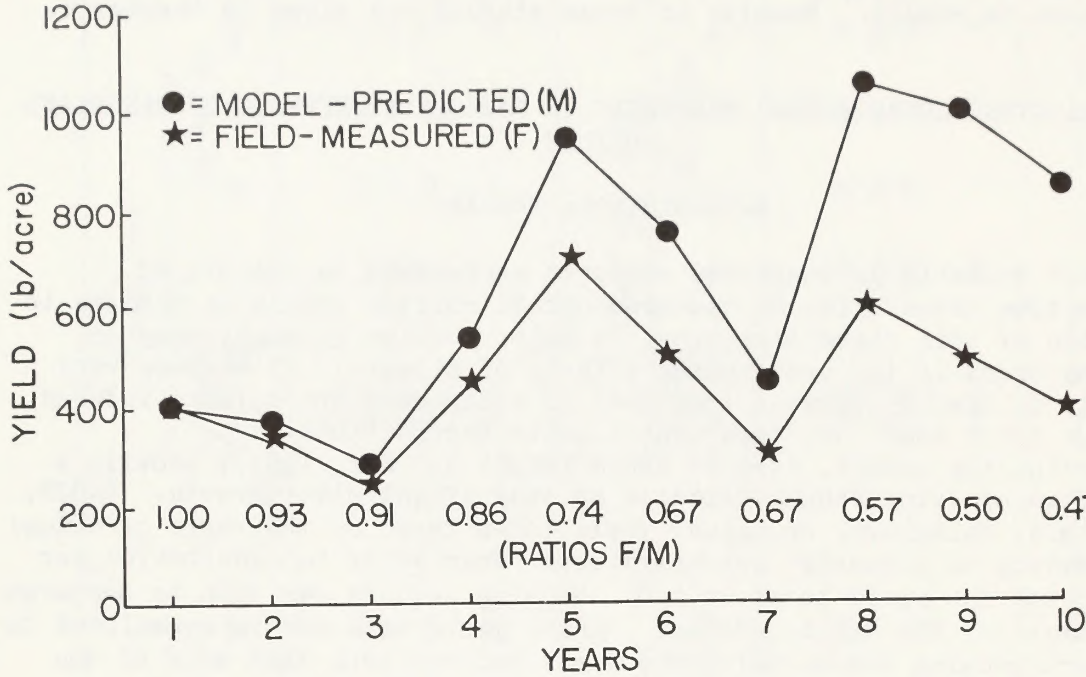


Figure 6.3a.--Hypothetical field-measured and model-predicted yield data and the annual F/M ratios.

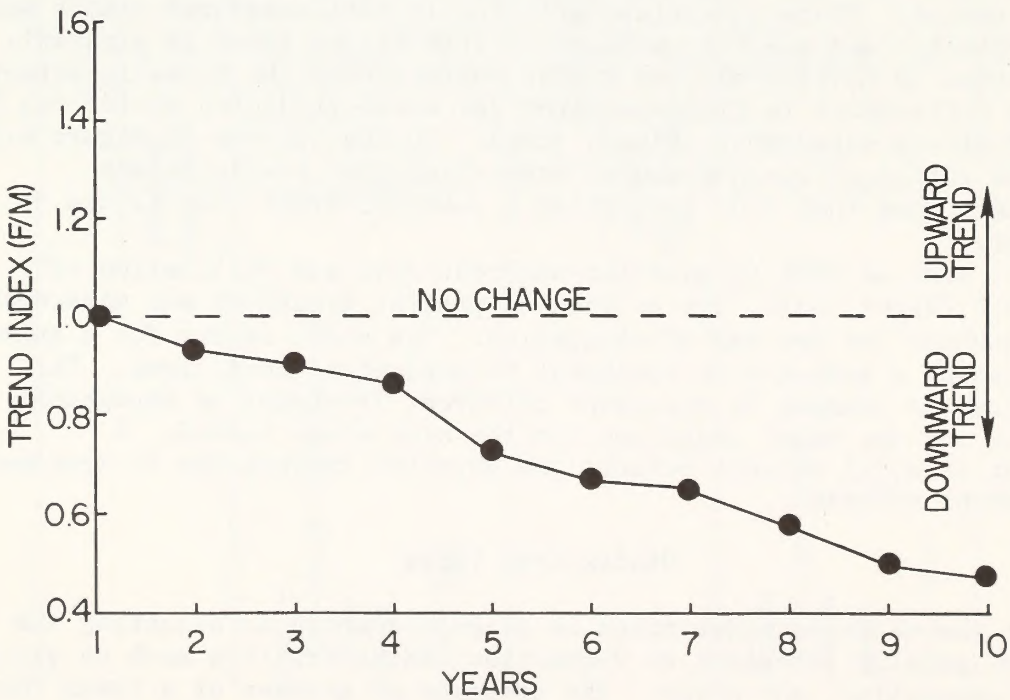


Figure 6.3b.--Plot of the annual field-measured/model-predicted (F/M) ratios from Figure 6.3a to indicate management induced trend.

question is asked, "What size of sample should be taken?" This is not a trivial question. Too large a sample would waste valuable resources. Too small a sample may negate potential conclusions and again waste human and time resources.

Several steps are common to all determinants of a sample size:

1. The desired limits of error or precision must be made, i.e., need to be accurate within a precision of ten percent of the population (true) mean;

2. An equation which will connect the sample size N with the desired precision of the sample;

3. The equation in 2 above will contain parameters and certain properties of the population that need to be estimated. For example, the assumption of a normal distribution and estimated population variance;

4. How is the area to be sampled subdivided? Possibly separate samples are to be made within sub-areas. The total sample is a sum of sub-samples;

5. Are more than one attribute or characteristic to be measured at sample sites? If different levels of precision are attached to each item then different sample sizes must be reconciled; and

6. Is the required sample size reasonable and consistent with available resources? The decision of a smaller sample which reduces precision must be made by the user as new questions based on sample design as methodology must be redone.

The estimation of sample size is one area of the more general statistical theories of sampling. General background and theory is available in many books. A more practical presentation is available in the reference, Statistical Methods by G. W. Snedecor (Snedecor and Cochran 1967).

Formulation

The precision desired in the sample estimates is a statement of the error we are willing to tolerate. Ideally, the estimated mean is within 10 percent of the population mean. This is written as

$$d = \bar{x} - \mu$$

where

$\bar{x}$ is the sample mean; and

μ is the population mean.

A level of confidence must be set which represents the chance we are willing to take so that the true mean is within d units of the sample mean.

Assuming that we are sampling from a normal distribution then the t - statistic is written as

$$t = \frac{\bar{x} - \mu}{s/n} = \frac{nd}{s}$$

where

s is the estimated standard deviation and n is the sample size;

as

$$n = t^2 s^2/d^2.$$

Methods are available to allow for a constraint of a unit cost for obtaining sample items.

Stochastic Models

Stochastic procedures are not in common use by range managers; however, some of these have been used at the Northwest Watershed Research Center, and have potential for future use. Discussion of these models and procedures have been used in water resources and are not found in range management literature.

Regression techniques can be used to investigate how previous year's variable values affect present year's values, which is termed serial correlation. This technique was used in a herbage yield study which indicated that the location's previous year's yield had an effect on the present year's yield, but that only the present year's growing season precipitation had an effect on the present year's yield (Hanson et al. 1982). In the same study, a Markov-Chain technique was used to determine how the previous year's yields would affect the present year's yield. Both the serial correlation and Markov-Chain techniques require long record length data sets which are only available from a few locations; however, if the data are available, statistical information can be obtained that can be used to enhance management decisions (Chow 1964; Haan 1977).

Another technique that is being used in our resource modeling efforts is generation of synthetic climate series. This is a procedure whereby a data set of daily temperatures, precipitation, or other driving variables are generated to drive resource models (Clarke 1973). The generated variable series has the same statistical attributes as those of the original series. These procedures can also be used to extend the climatic record period or to obtain records where there are no data. Where no data are available, regional parameter values are used to generate the

synthetic series. These procedures are very useful for determining the outcome of different management strategies. (Nicks and Harp 1980; Richardson 1981).

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Chapter 7

RANGELAND MODELING

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Chapter 7

RANGELAND MODELING

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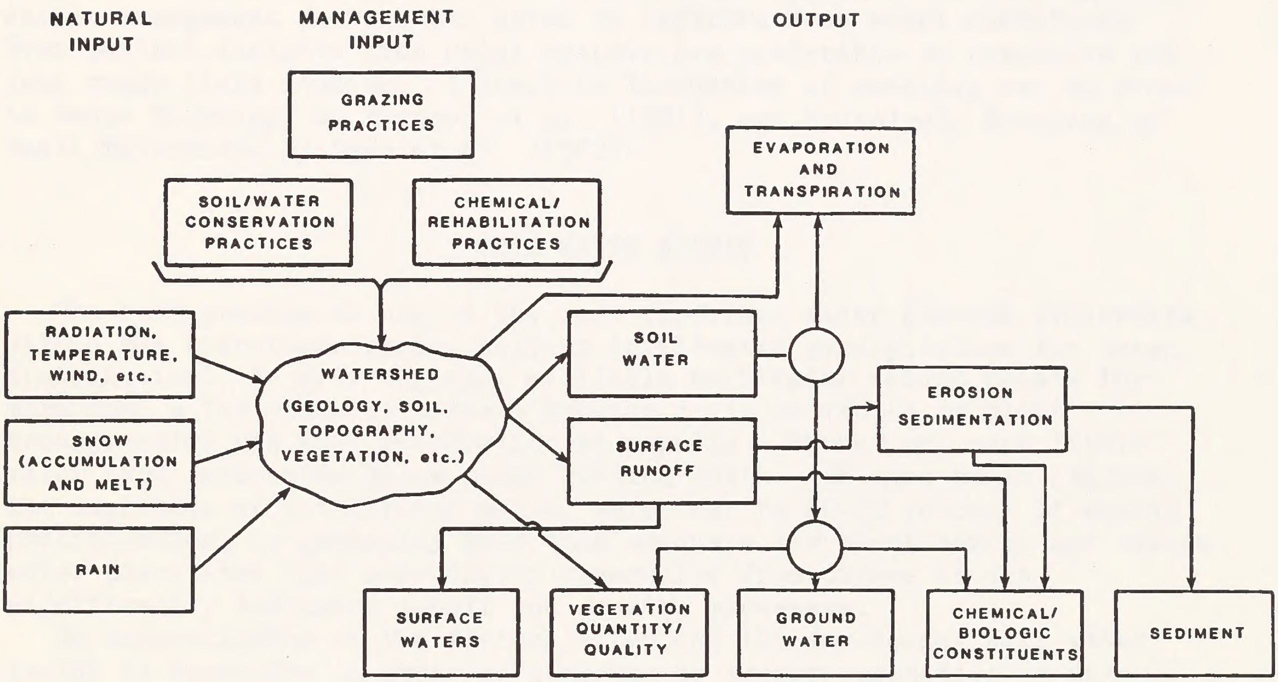


Rangeland Watershed Resource Model

Flowchart

INTRODUCTION

Rangeland hydrologic models provide a basis for applying results from study areas to other areas where management decisions on rangeland resources and uses are required. Models are generally a quantitative expression of what is being observed or predicted. Mathematical models are the key to hydrologic models. Even though imperfect, conceptual models of the complex hydrologic processess in operation on a rangeland watershed provide insights into the relationship and interactions between components of the natural system. Changes in important resource factors due to management factors can often be inferred from model operations. Even partial insights from model outputs are preferable to expensive and long range field studies. A complete discussion of modeling can be found in Range Hydrology by Branson et al. (1981), and Hydrologic Modeling of Small Watersheds by Haan et al. (1982).

SOIL WATER MODELS

The soil profile is one of the most important water storage reservoirs within the hydrologic cycle, holding infiltrated precipitation for later distribution. In arid regions, available soil water seldom exists for more than a few weeks at a time, because it is extracted by plant transpiration and soil evaporation so rapidly. Therefore, very little water ever percolates below plant rooting depth. In more humid regions, the magnitude of infiltrated water, which may be 80-90 percent of annual precipitation, is generally more than adequate for plant needs, and excess water percolates into groundwater reservoirs from whence it can significantly influence runoff and erosion processes.

An understanding of the factors affecting the day-to-day soil water status is necessary in order to increase or modify vegetative or water yields, including such range improvements as reseeding projects or livestock water developments. This time distribution of soil water within the portion of the soil profile that supplies plant roots is a complex interaction of many variables related to present and historical climate, plants, and parent soil materials. Although soil water principles have been studied for many years, only recently has a complex systems approach to the prediction of soil water status begun. Mathematical modeling techniques which rely on the use of modern computer capability and automated data acquisition equipment have been developed to provide a comprehensive quantitative description of the behavior of the soil-water-plant system.

Literature searches by Hildreth (1976, 1978) indicated that many mathematical simulations or computer models have been developed to assess soil water status. However, most of these models were developed to satisfy a particular need (i.e., spring wheat yield predictions in the northern Great Plains) and may not represent other crops or locations. None of the models were specifically developed for use on western rangelands so as to include the effects of transpiration from grasses, brush, and forbs on soil water, although some of the more general models may be adaptable to such conditions.

Two models were selected for testing based on the criteria that they should be: (1) general enough to be adaptable to range conditions; (2) tested against field data, even though for cultivated crops; (3) readily available; and (4) representative of different levels of complexity and data requirements. The models selected were the ERHYM (Ekalaka Rangeland Hydrology and Yield Model) developed by Wight and Neff (1983) and the SPAW (Soil-Plant-Air-Water Model) developed by Saxton, Johnson, and Shaw (1974). The objectives of this study were to determine: (1) if existing models with soil water accounting procedures included could be adapted to western rangeland conditions; and (2) what level of sophistication is necessary to obtain adequate estimates of daily soil water status for various rangeland watershed applications.

Model Descriptions

Wight's model is relatively simple and requires about the minimum of input information. Saxton's model, on the other hand, attempts to treat in some detail, all of the physical processes and interactions involved. As such, it requires more information on initial boundary conditions and limits. However, both use essentially the same hydrologic and meteorological data.

ERHYM

[The following description is a summary of material found in the ERHYM User's Manual, Wight and Neff (1983).] This model was developed for use in predicting runoff and herbage production for northern Great Plains rangelands (mainly grasses). It provides daily runoff, soil water evaporation, transpiration, and soil water routing for up to four layers at a range site. Applications include utilization of real-time climatic data to simulate ongoing processes, or utilization of historical climatic data to simulate soil water status under a range of climatic conditions and management practices. It can be run on a seasonal basis, with new soil water boundary conditions required at the start of each season, or continuously, utilizing a simple snowmelt-temperature relationship to account for snowfall storage, snowmelt infiltration, and runoff. The model computes snowfall, snowmelt, infiltration and runoff from daily precipitation and temperature. It uses the SCS curve number method (USDA, SCS 1972) to determine runoff, and a constant times temperature procedure for snow accumulation and melt (Stewart et al. 1975). The evapotranspiration, soil water status, and herbage yield calculations are from Wight and Hanks' work (1981).

As described by Smith and Williams (1980), the SCS curve number technique (USDA, SCS 1972) was selected for predicting runoff from daily precipitation because: (1) it is a familiar procedure that has been used for many years in the United States; (2) it is computationally efficient; (3) the required inputs are generally available; and (4) it relates runoff to soil type, land use, and management practices. All of the precipitation that does not become runoff is assumed to either be stored as snow or infiltrates into the soil profile. The soil profile is divided into as many as four layers depending on genetic horizons and soil characteristics. The model then functions as a series of cascading reservoirs (one for each layer); that is, all of the water infiltrated is assumed to be stored in the first layer until it reaches its field

capacity, at which time any additional infiltration is assumed to be stored in the second layer, and so on.

The evapotranspiration portion of the model is essentially the same as that used by Wight and Hanks (1981). Potential evapotranspiration is first calculated using the Jensen and Haise (1963) equation, which assumes a full cover of alfalfa with water nonlimiting. The potential evapotranspiration from rangeland is then obtained by multiplying the value determined above by a range crop coefficient. Actual transpiration is estimated by multiplying the potential evapotranspiration for the range site by a site specific transpiration coefficient and a relative growth curve factor. Soil evaporation is a function of potential soil evaporation and time since the soil surface was last wet; potential soil evaporation being the difference between potential evapotranspiration and the actual transpiration. Soil evaporation is limited to water in the top 12 inches of the soil profile that is in excess of air-dry soil water content, which is less than the lower limits of soil water availability (permanent wilting point).

As the model operates, water is added to the soil by precipitation and removed by transpiration, evaporation, and drainage. The soil profile is divided into genetic horizons, and water is added or subtracted from one soil layer at a time. If, following a rain, the water content of the surface layer exceeds field capacity, water is added to the next layer and so on until all precipitation minus runoff is accounted for or until all soil layers are filled. Excess soil water is counted as drainage.

Soil water extraction also proceeds one layer at a time beginning at the surface layer. If the surface soil layer cannot, under the imposed constraints, supply enough water to meet daily transpiration, the model then extracts water from the second layer and so on until transpiration has been satisfied or until all layers have been depleted.

SPAW

(The following description is a summary of material found in the SPAW Users Manual, Saxton, Brooks, and Richmond, in progress.) The SPAW model computes a daily estimate of the soil water profile, actual evapotranspiration, and deep percolation. Figure 7.1 illustrates with arrows the major components considered in the water budget, for a unit of space as noted by the dashed boundaries. Daily estimates are made of all quantities except redistribution of soil water which occurs at a maximum time step (usually 1 to 4 hours) to maintain computer stability.

The soil profile is represented by a user selected number of layers to reflect the average soil profile over the field or watershed being studied. Each layer may be assigned a unique depth and set of water characteristic curves (tension and conductivity). The above-ground portion is assumed to be a uniformly distributed plant canopy which also represents average conditions over the study area.

The computational sequence for the model is shown in schematic block diagram form in Figure 7.2. The first step is to combine an independently determined value of potential evapotranspiration with an input variable or coefficient to produce an estimate of actual evapotranspiration. Intermediate computations separate the actual evapotranspiration into principle components of interception evaporation, soil water evaporation, and plant transpiration. After subtracting the actual evapotranspiration from existing soil moisture, by layers, daily infiltration is added. Then soil water is redistributed among the soil layers, including deep percolation.

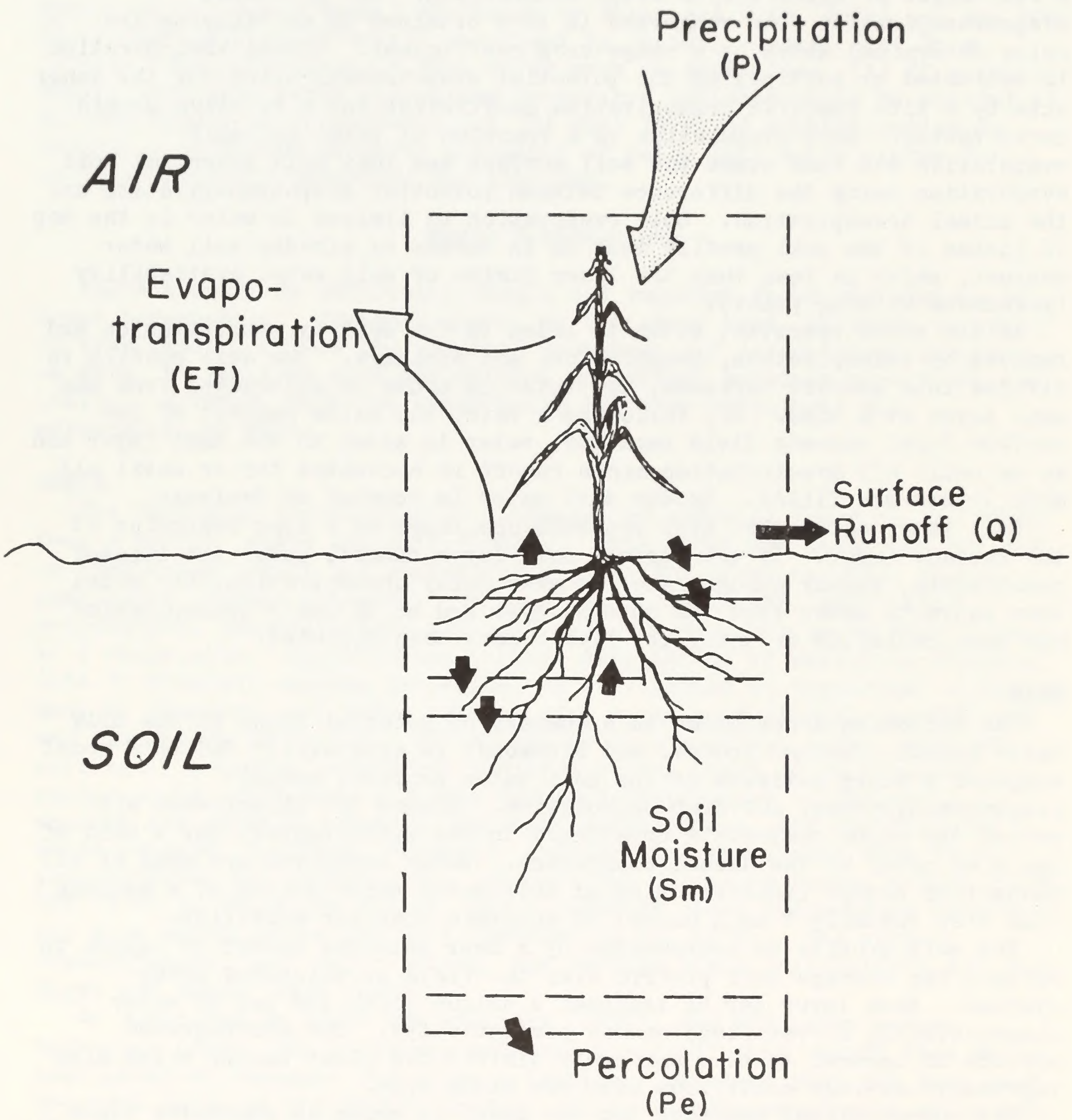


Figure 7.1.--Schematic diagram to illustrate area of consideration and water budget components for the SPAW model (from Saxton et al., in progress).

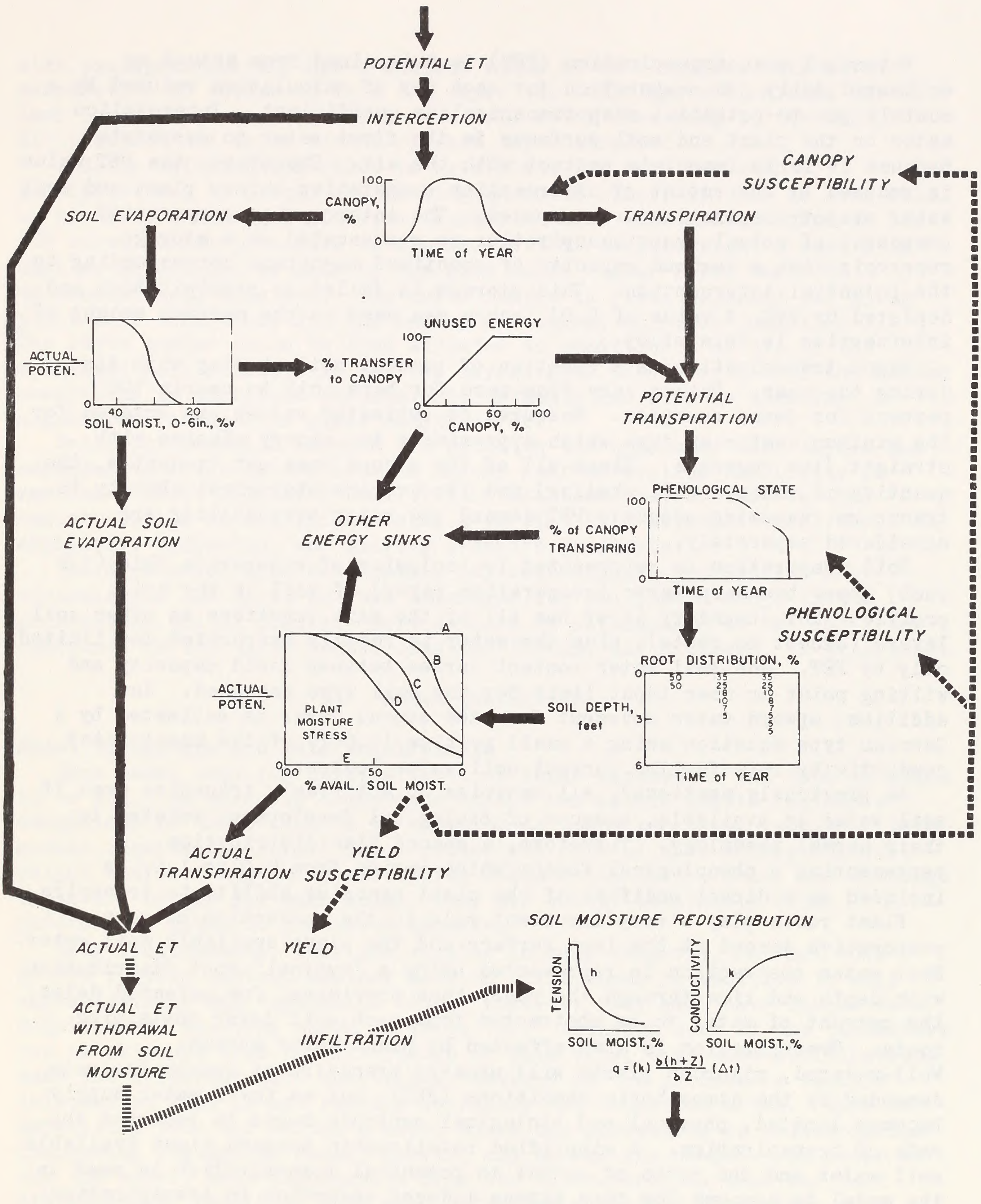


Figure 7.2.--Schematic representation of the expanded Soil-Plant-Air-Water (SPAW) model (from Saxton et al., in progress).

Potential evapotranspiration (PET) is determined from actual or estimated daily pan evaporation for each day of calculation reduced by a monthly pan-to-potential evapotranspiration coefficient. Interception water on the plant and soil surfaces is the first water to evaporate because it is in immediate contact with the air. Therefore, the PET value is reduced by the amount of interception evaporation before plant and soil water evapotranspiration are computed. The interception evaporation component of actual evapotranspiration is represented as a storage reservoir with a maximum capacity of specified magnitude corresponding to the potential interception. This storage is filled by precipitation and depleted by PET. A value of 0.01 inches was used as the maximum amount of interception in this study.

Plant transpiration is a function of percent soil shading with time during the year. Values vary from zero for bare soil to nearly 100 percent for dense canopies. Measured or estimated values are entered for the minimum number of days which approximate the canopy changes with straight line segments. Since all of the canopy does not transpire, the quantity of canopy (soil shading) and its average biological ability to transpire, assuming adequate PET demand and water availability are considered separately.

Soil evaporation is represented by inclusion of a separate thin (1/2 inch) upper boundary layer (evaporation layer) of soil in the soil profile. This boundary layer has all of the same functions as other soil layers (except no roots), plus the water is readily evaporated and limited only by PET. The soil water content varies between field capacity and wilting point or user input limit for the soil type assigned. In addition, upward water movement from the second layer is estimated by a Darcian type equation using a small portion (0.001) of the unsaturated conductivity rate for the current soil water content.

As previously mentioned, all canopies do not freely transpire even if soil water is available, because of biological development related to their normal phenology. Therefore, a second time distribution representing a phenological factor which varies from 0.0 to 1.0, is included as a direct modifier of the plant canopies ability to transpire.

Plant roots play a very important role in the connection between evaporative demand at the leaf surface and the plant available soil water. Root water abstraction is represented using a "typical" root distribution with depth and time through the year, thus providing, for selected dates, the percent of water to be abstracted from each soil layer containing roots. Transpiration is also affected by plant water stress. Well-watered, vigorous plants will usually transpire at nearly the rate demanded by the atmospheric conditions (PET), but as their water supply becomes limited, physical and biological controls begin to restrict the rate of transpiration. A simplified relationship between plant available soil water and the ratio of actual to potential transpiration is used in the model to account for this stress induced reduction in transpiration. In the SPAW model these relationships are applied independently to each specified soil layer and the transpiration of that layer is a multiple expression of the potential evapotranspiration, canopy, phenology, and the percent roots, reduced by the water stress relation.

A daily estimate of actual evapotranspiration, thus, is obtained by adding the components of interception evaporation, soil water evaporation, and plant transpiration. Interception evaporation occurs only on days

with precipitation and has a maximum value of 0.01 inches, soil water evaporation as estimated from the upper two soil layers (includes the 1/2 inch layer), and transpiration from soil water according to the root distribution and water stress of each layer involved.

A daily infiltration value is determined for each day with precipitation, by simply subtracting measured runoff if data is available, or by using a modified SCS curve number method. The modification to the SCS curve number procedure is similar to that used in Wight's model, in that an adjustment is made to the site curve number value based on antecedent soil moisture. The curve number is first selected for given plant-soil conditions and the median antecedent moisture condition II. The curve number value is then adjusted to condition I or III if the estimated soil moisture in the top layers goes below, or above, the median conditions by specified amounts. Adjustments can also be made for significant changes in plant canopy cover.

Daily infiltration amounts are added to the uppermost soil layers and cascaded to lower layers as each layers near-saturation capability is reached. After all daily infiltration has been distributed, further redistribution is determined using a Darcian soil moisture model based on capillary, hydraulic, and gravity pressure gradients.

The SPAW model does not contain any mechanism to account for snow accumulation and melt, and was developed for cultivated crops in the mid-western United States. More details on all aspects of the model are contained in the users manual (Saxton, Brooks, and Richmond, in progress).

Model Evaluation

Model Parameters and Data Requirements

Each model requires certain types of input parameters and data to allow it to run. An adequate comparison of the two models should include a comparison of these factors in addition to comparing final results. Both models require the normal input parameters such as unit device numbers, output options, beginning and ending computation dates, etc., and although these are unique for each model, they are easily obtainable from information given in the users manuals.

Data requirements, too, are similar in many respects, in that both models require certain weather data to drive them, in addition to soil characteristic and vegetation data. However, they each have unique data requirements also, as shown in Table 7.1. Although most of the parameters can be obtained from the literature or data sets, with some modifications made for different site conditions, several of the parameters require information that is not readily available for rangeland sites. This is especially true for Saxton's model where six parameters or relationships concerning vegetation roots, growth, and stress are needed. In order to run the model, some information from the literature was used for root distribution, realizing that such data were collected from sites with different climatic and soil characteristics. Canopy and phenology curves were developed from vegetation measurements made at Reynolds Creek, also knowing that these data do not represent potential unstressed conditions. The canopy and phenology susceptibility curves, and the moisture stress curves were used as presented by Saxton, even though these were developed from studies based on irrigated crops in the Midwest.

Table 7.1.--Input requirements for running SPAW and ERHYM soil water balance models.

SPAW MODEL	ERHYM MODEL
Initial soil moisture	Initial soil moisture
Daily precipitation	Daily precipitation
Daily runoff or curve number	Curve Number
Daily pan evaporation	Daily max & min temperature
Monthly pan coefficient	Daily solar radiation
Annual pan evaporation	---
Soil type by layer	Soil characteristics by layer
Layer thickness	Layer thickness
Δ time interval	---
Δ soil pressure tolerance	---
Soil water evaporation percent	---
Soil freezing	---
Root distribution	Soil temperature curves by layer
Canopy cover curve	Crop coefficient
Canopy susceptibility	---
Phenology curve	Plant growth curve
Phenology suceptibility	---
Moisture-stress curves	---
Planting & harvest dates	Starting growth date

In using Wight's model, three factors require data that are not readily available. Of these, the plant growth curve, which is similar to the phenology curve in Saxton's model, is the most difficult to make site specific, for the same reasons previously discussed. Data to develop soil temperature curves by layer are also lacking, (if the model is to be used for areas with a climate different than Ekalaka where the included soil temperature relations were derived); however, some models based on air temperature are available, and since the temperature of the deeper layers varies only slightly through the year, these curves can be estimated with some confidence. The third factor not readily available is the crop coefficient, which is merely a ratio of transpiring canopy to total canopy cover. Changes in this ratio of up to 50 percent made only minor changes in total soil water at years end; therefore, at least in this case, great accuracy was apparently not required in this factor.

Description of Study Sites

The two sites selected for use in this evaluation are part of the Reynolds Creek Experimental Watershed in southwestern Idaho. These watersheds were selected because of data availability, and because they represent "typical" rangeland sites found in the western United States. The sites vary somewhat in elevation, size, vegetation, soils and climate as shown in the summary of site characteristics presented in Table 7.2.

Two additional sites were originally selected for use in the model evaluation to represent a wider variety of rangeland conditions. However, precipitation data had not been processed at one site, lying between the Flats and Lower Sheep sites, and Saxton's model does not contain a means of dealing with snow accumulation and melt, which plays a significant role in the water regime at the higher elevation site (elevation 6800 feet).

Model Calibration

Both models were first run on data from the Flats site for the 1979 calendar year using parameter values based on previous experience, site characteristics, or best estimates. After the initial runs, some model parameters were adjusted, as deemed necessary, to better match observed soil moisture trends and totals. Once model determined values matched observed values, as close as possible, the model was assumed to be calibrated for that site. The model was then run for the total period of adequate record (1976-1981). Since this record contained rather wet and dry years in contrast to the year chosen for initial calibration, a few minor parameter adjustments were again made so that overall performance of the model provided the best fit to the observed data.

Results obtained from the two models after final adjustments were made, are presented in Table 7.3 for individual layers and for the total profile, for each year. The runs were made for each year individually, that is, the initial soil moisture values were set equal to the last measured values for the previous year (usually near December 27 or 28), and the model was run for the entire year as driven by observed temperature, precipitation, and radiation data. The four soil layers used (0"-9", 9"-18", 18"-30", and 30"-54"), were selected on the basis of data availability rather than soil characteristics. The most significant changes in soil characteristics occurred at 10, 17, and 26 inch depths at the Flats site, and at 15, 20, and 23 inch depths at the Lower Sheep site. However, soil moisture data had been collected for several years so as to represent the moisture conditions in the four layers shown in the table,

Table 7.2.--Comparison of watershed characteristics at two Reynolds Creek study sites.

Characteristic	Flats	Lower Sheep
Size	2.24 Ac.	33 Ac.
Elevation	4000 ft.	5400 ft.
Avg. Slope	5%	16%
Aspect	N	NW
Soils		
Subgroup	Typic Haplargids	Calcic Argixerolls
Family	Fine loamy mixed, mesic	Loamy skeletal mixed
Series	Nannyton loam	Searla gravelly loam
Geologic Material	Sedimentary	Basalt
Vegetation	Bottlebrush Cheat Grass Shadscale Squirreltail	Sandberg bluegrass Low sagebrush
% Vegetative Cover	25	25
Average Precip.	10 inches	14 inches
SCS Hydrologic Class	B	B
SSF Rating (8 yr avg. grazed)	19	24

Table 7.3.--Soil water contained in specific layers, and in the total soil profile (0-54 inches), at the end of each year (1976-1981), at the Flats (in inches).

	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW
0-9"	.9	1.18	1.18	2.2	2.20	2.34	1.8	1.59	1.74	1.6	1.31	1.67	2.2	1.97	1.91	2.2	2.41	2.47
9"-18"	.9	1.16	1.22	1.9	1.97	1.88	.9	1.41	1.37	1.1	1.27	1.31	1.8	1.61	1.44	2.5	2.36	1.92
18"-32"	1.5	1.40	1.60	1.4	1.62	1.97	2.7	1.71	1.68	1.6	1.73	1.70	1.6	1.77	1.73	1.9	1.85	1.76
32"-54"	3.0	2.93	3.14	2.9	3.10	3.35	3.2	3.20	3.27	3.1	3.35	3.31	3.3	3.29	3.25	3.2	3.47	3.15
Total	6.3	6.67	7.14	8.4	8.89	9.54	8.6	7.91	8.06	7.4	7.66	7.99	8.9	8.64	8.33	9.8	10.09	9.30
Difference	-.37		+.47	-.49		+.65	+.69		+.15	-.26		+.33	+.26		-.31	-.29		-.79
% Difference	5.5		7.0	5.5		7.3	8.7		1.9	3.4		4.3	3.0		3.6	2.9		7.8

and thus provided the basis of comparison. As noted, differences between model estimates and observed values for the individual layers, and years, are generally small. The largest deviations are found in the upper two layers where most of the activity takes place. In all cases, even though individual layer values may be off somewhat, the total annual soil water for the entire soil profile is within less than 10 percent of the observed value. This occurs because of compensating differences between the different layers, and the inherent bookkeeping procedures contained in the models. The differences are somewhat greater for the ERHYM model in this case.

A better evaluation would be to compare model predicted soil water with observed soil water throughout the year, since conceivably the year-end totals could be close, but the annual trends could be out of phase. A continuous record as estimated by the models and the observed soil water at approximately two-week intervals is shown in Figures 7.3 through 7.8 for the period 1976-1981 at the Flats site. As indicated in the discussion of Table 7.3, and better depicted in these figures, the major changes in soil moisture occur in the upper two layers. In fact, the changes in the lower two layers are very minor except during the first half of 1978, where observed soil moisture increased somewhat (about 1 inch). Both models also indicated an increase in this layer at, or near, this time, suggesting that they are properly accounting for the infiltration that occurred then. The SPAW model seemed to best follow the observed trend in magnitude although it indicates the increase starting before it was observed. This is probably due to the inability of the SPAW model to account for storage in the form of snow which delayed the entry of the water into the soil. The ERHYM model followed the actual timing of the soil water increase better, but differed considerably in the magnitude of the change, predicting it to be about 2 1/2 inches rather than the 1 inch observed. Activity in the lowest layer was depicted better by ERHYM, especially in timing, probably because of the snow accounting procedure it contains.

In general, both models follow the observed data quite well, one being a little better one year or in a certain period, but the opposite being true for another year or period. Overall, the results appear similar to those presented in Table 7.3, which indicate both models performed about equally for the six years of testing.

Model Comparison and Summary

Validation of the models consisted of using the information gained during calibration, concerning operation of the models and range of parameter values applicable to rangeland conditions, to test the models at a new site where climate and watershed characteristics differed from the calibration site. In applying the models to the new site, called "Lower Sheep", only physical parameters related to watershed characteristics were changed, rather than adjusting coefficients and parameters to provide a best fit, as was done in the calibration runs. The growth or phenology curves were delayed 15 days to account for the cooler climate, but shape and length of growing season remained the same.

Results of the model runs at the Lower Sheep site are presented in Table 7.4. Again both models produced reasonably good results. The differences between the observed and calculated soil moisture values are slightly greater for some years than those obtained at the Flats site, but the maximum difference was still only 14 percent. Further analysis of

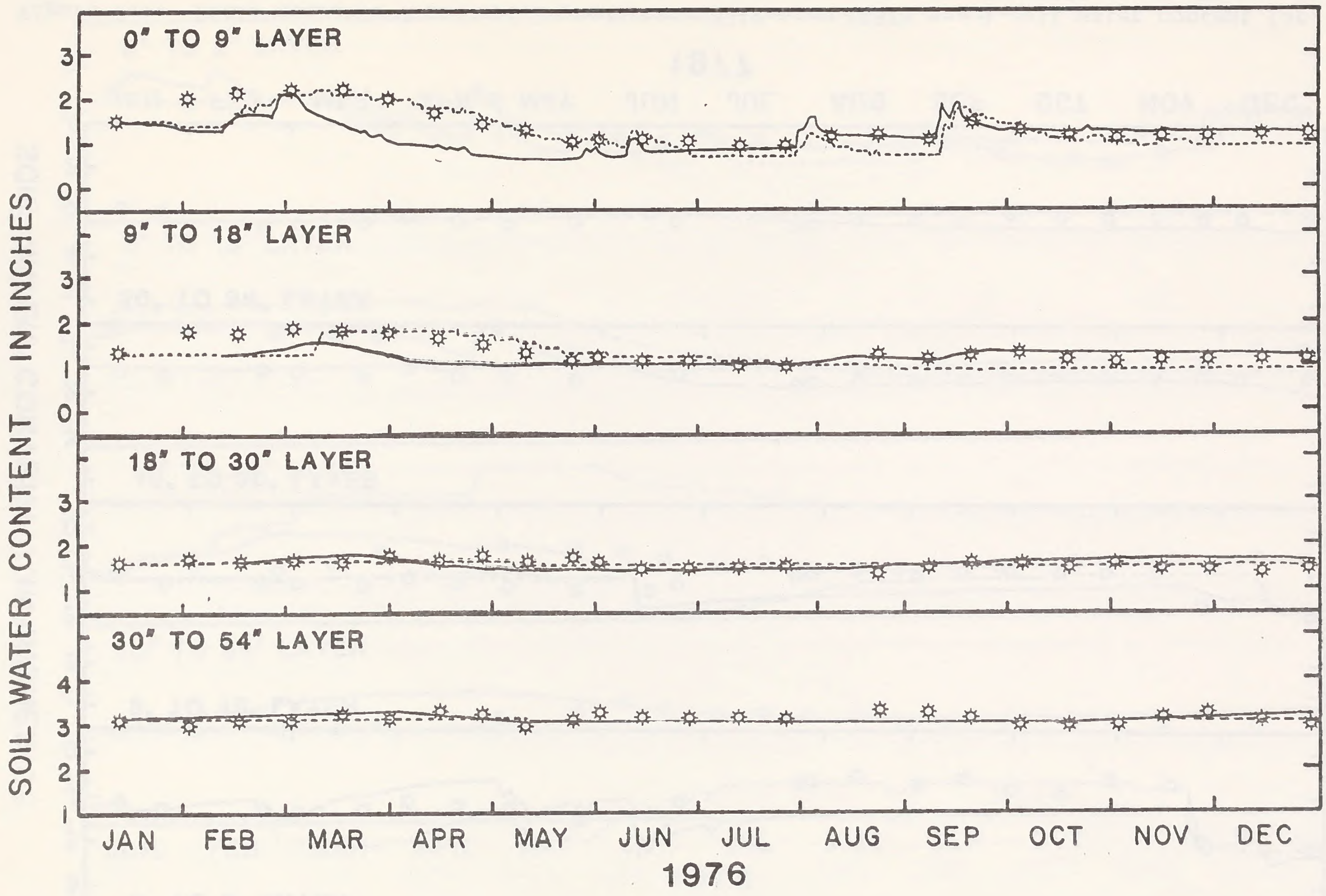


Figure 7.3.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1976 at the Flats site.

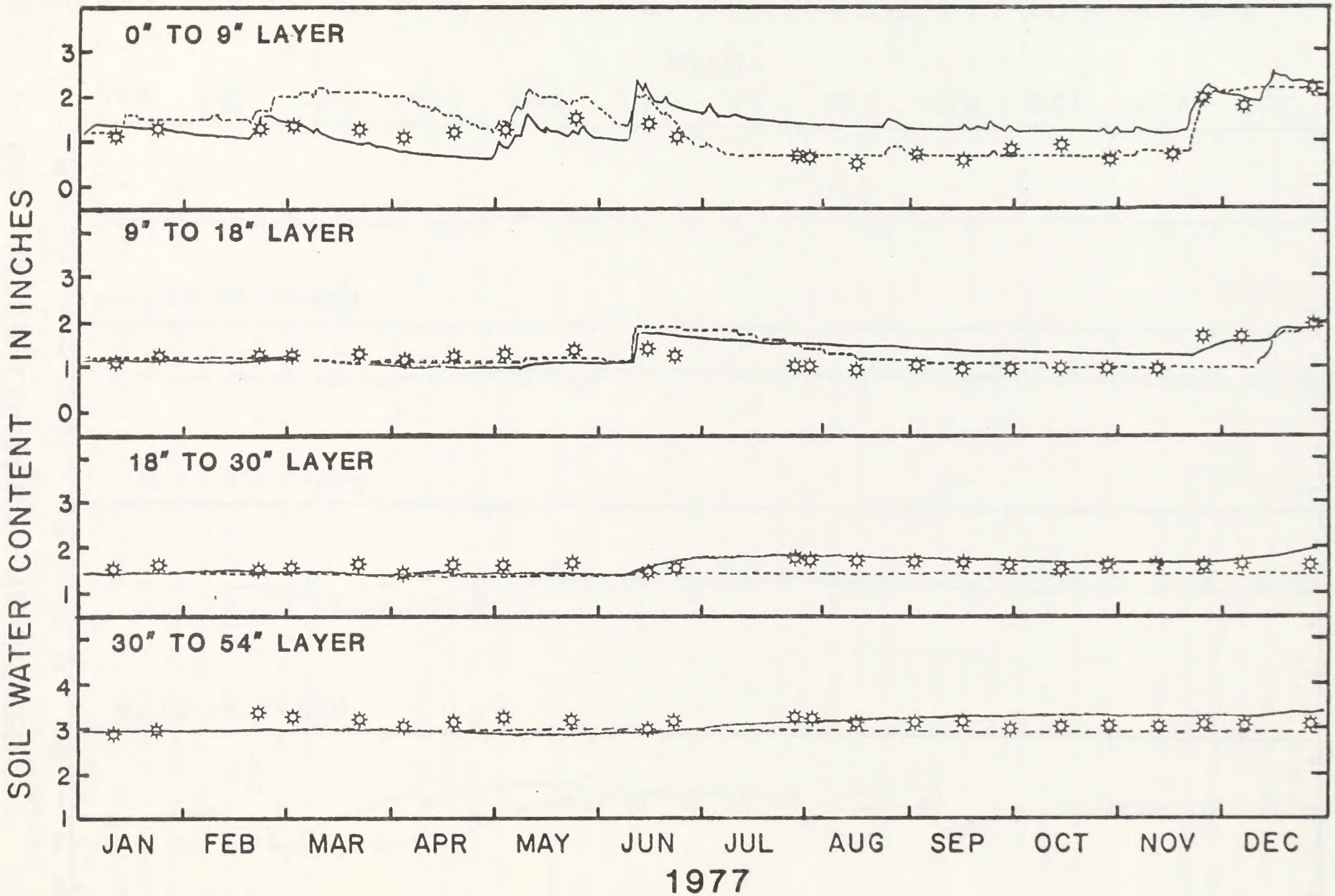


Figure 7.4.--Field measured ☼ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1977 at the Flats site.

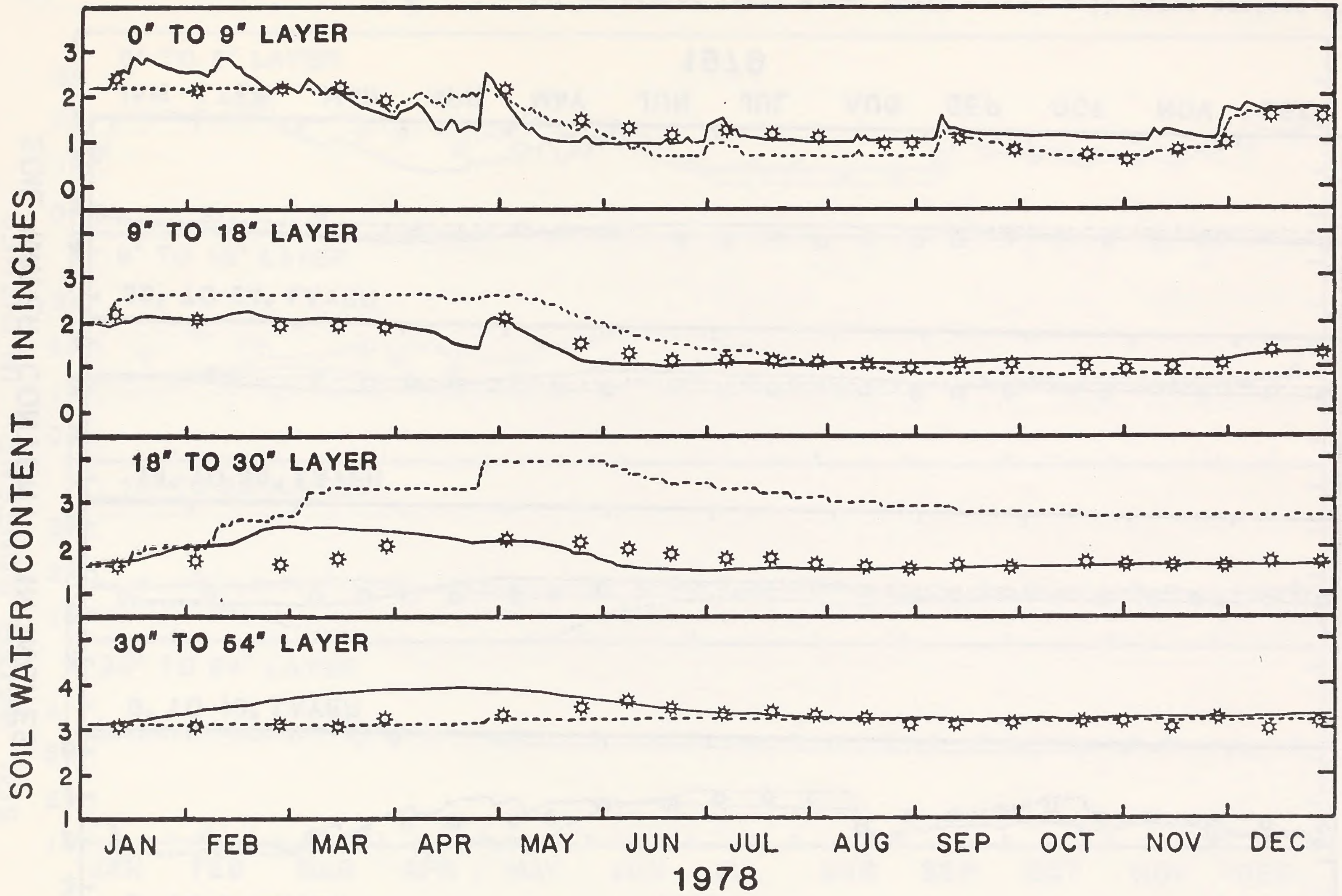


Figure 7.5.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1978 at the Flats site.

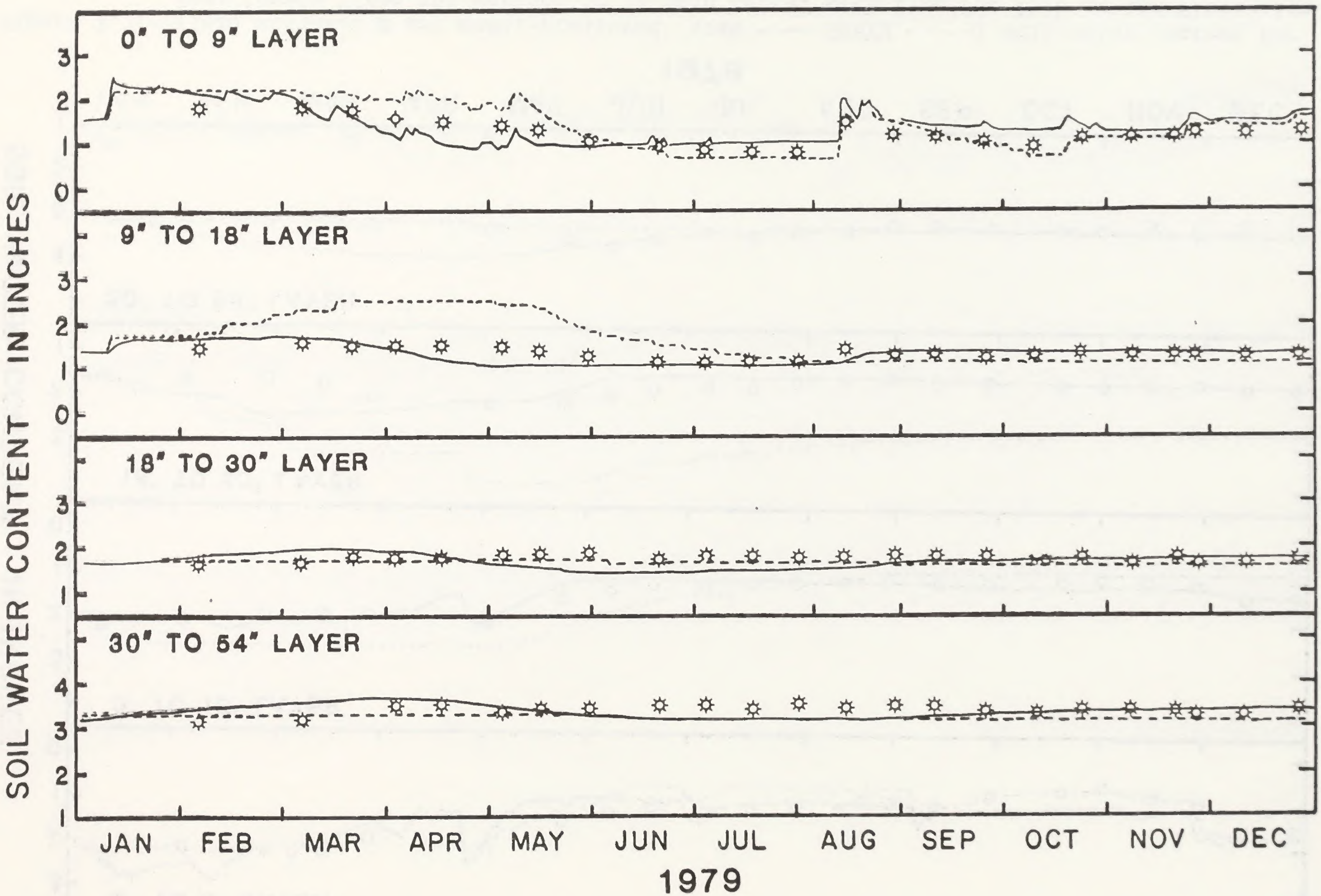


Figure 7.6.--Field measured ☼ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1979 at the Flats site.

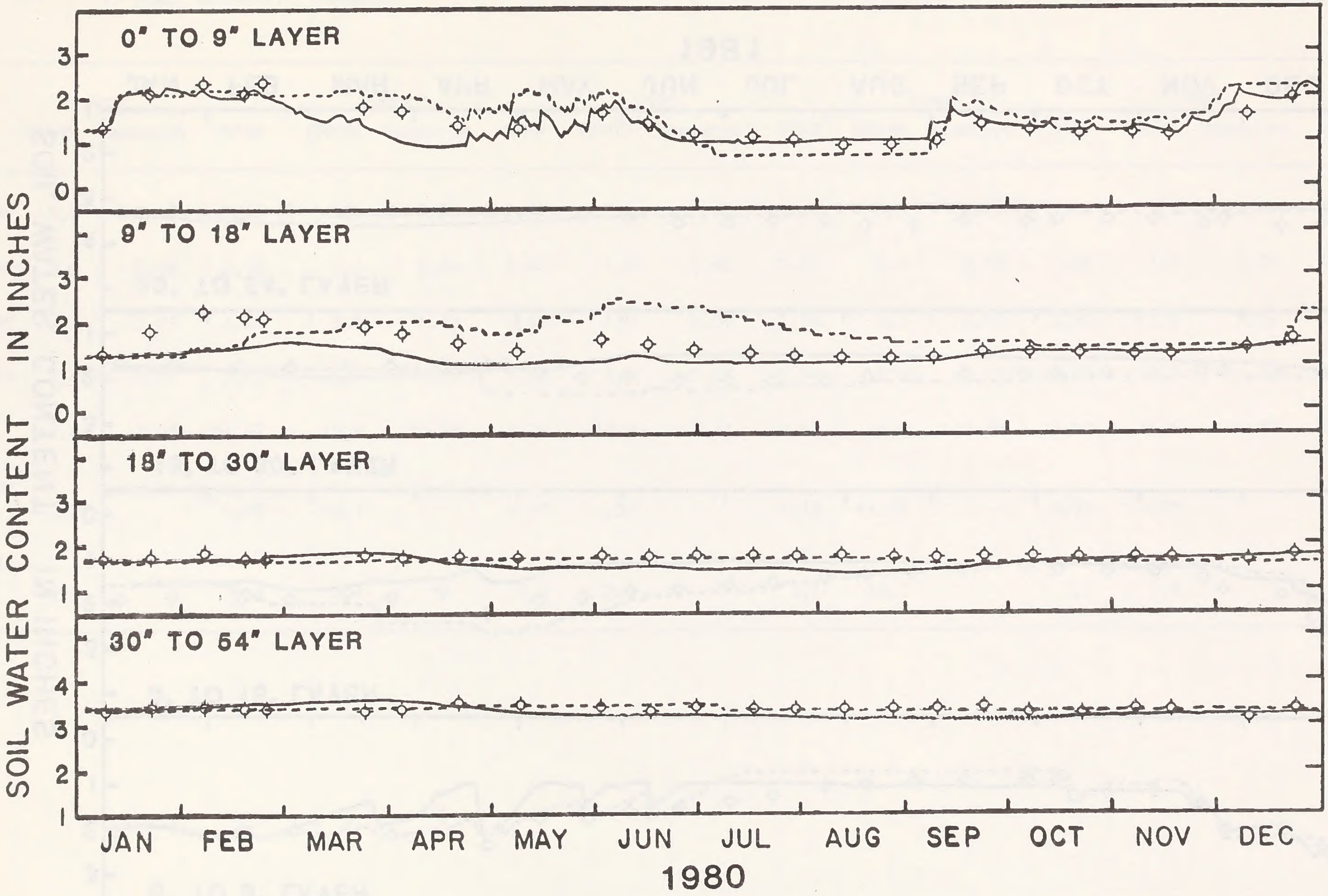


Figure 7.7.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1980 at the Flats site.

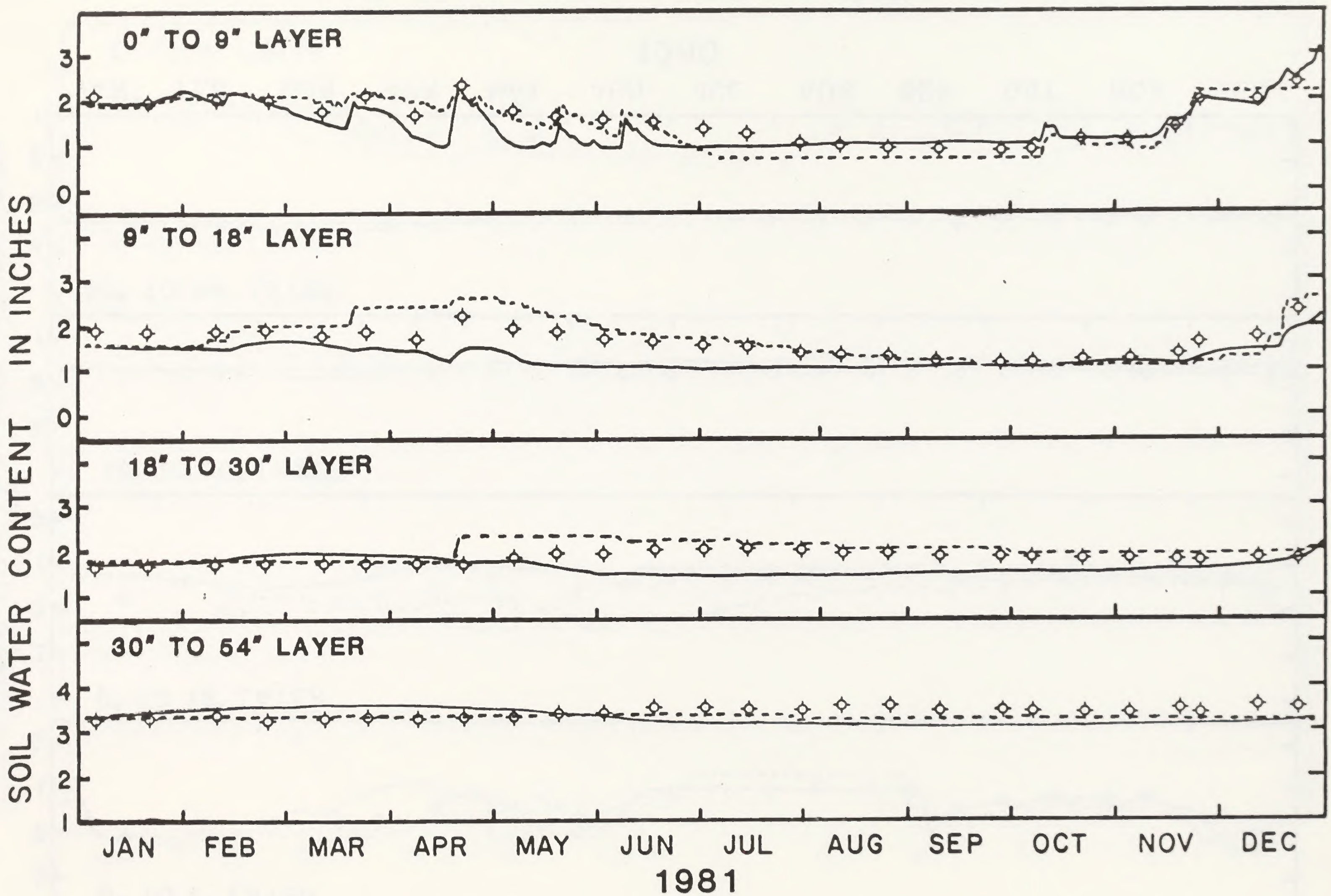


Figure 7.8.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = - - -) soil water content for four layers, from the surface to 54 inch depth, with time for 1981 at the Flats site.

Table 7.4.--Soil water contained in specific layers, and in the total soil profile (0 to 54 inches) at the end of each year (1977-1981) at Lower Sheep (in inches).

	1977			1978			1979			1980			1981		
	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW	ERHYM	Measured	SPAW
0"-9"	3.3	2.67	2.66	3.0	2.35	2.39	2.9	2.48	2.40	3.3	2.43	2.38	3.3	3.24	2.86
9"-18"	3.0	2.78	2.65	1.7	2.25	2.40	1.8	2.56	2.21	2.3	2.25	2.25	3.3	3.30	2.74
18"-32"	2.9	3.21	3.64	3.0	3.18	3.52	3.0	3.09	3.38	3.3	2.97	3.39	3.8	3.89	4.14
32"-54"	5.4	5.37	5.67	5.9	5.81	5.98	5.4	5.28	5.84	5.8	5.23	5.78	5.2	6.10	6.38
Total	14.6	14.03	14.62	13.6	13.59	14.29	13.1	13.41	13.83	14.7	12.88	13.80	15.6	16.53	16.12
Difference	+.57		+.59	+0.1		+.70	-.31		+.42	+1.82		+.92	-.93		-.41
% Difference	4.1		4.2	0.1		5.1	2.3		3.1	14.1		7.1	5.6		2.5

results presented in Tables 7.3 and 7.4 indicate that values produced by ERHYM vacillate from greater to less than observed more than do SPAW values, but ERHYM long-term averages are actually closer to observed averages. Regression analysis between model predicted soil moisture and measured soil moisture, on each day of observation provides another way to compare "goodness of fit", shown in Table 7.5. Presented are: 1) the regression equations for both models and sites, for individual years; 2) the regression equations for all years combined at each site for both models; and 3) the regression coefficient R^2 associated with each equation. ERHYM predicted values are found to correlate better with the approximately 26 biweekly observations than do SPAW predicted values, in all but one year.

This is in contrast to results shown in Tables 7.3 and 7.4, where water content by layer and profile at the end of each year as predicted by ERHYM generally differ more from observed values than SPAW predicted values did. This indicates that the trends between observed soil water changes and ERHYM calculated changes are similar even though the magnitude of actual values may be different. Precipitation falling as snow may cause the reduced correlations observed for the SPAW model. In other words, the trend between observed conditions and SPAW predicted conditions could be opposite at times, because snowfall occurred, but was handled by the SPAW model as rain. This would cause the SPAW predicted soil moisture to show an increase when observed soil moisture indicated no change, the water still being stored at the surface as snowpack. Later as the snow melts, observed soil moisture would increase while SPAW predicted values would remain unchanged, or even decline if evaporative demands were present. This out-of-phase soil moisture accounting would occur in late fall and winter, and can be observed somewhat in the top layer of Figures 7.5 and 7.8.

Figures 7.9 through 7.14 show a continuous record of the total soil water in the 0 to 54 inch profile, as calculated by the models, and the observed soil water on approximately a biweekly interval, at the Flats site for the years 1976 through 1981. As shown, both models follow the general trends indicated by the observed data. Although it appears that the ERHYM model results follow the observed data slightly better than the SPAW model, there are individual years, or periods within a year, where the reverse is true. Figures 7.9 through 7.14 are similar to Figures 7.3 through 7.8 except total water within the profile is shown, rather than individual layer values. Both sets of figures are shown to illustrate that trends and model response can be depicted by either method. The reason that the response is similar is probably due to the fact that almost all of the activity takes place in the upper layers, and adding the essentially constant lower layers changes the magnitude, but not the trends. Therefore, only total profile results are presented in later Figures. Figures 7.15 through 7.19 show the soil water content in the 0 to 54 inch profile as predicted by the models, and observed, for 1977 through 1981 at the Lower Sheep site. These figures represent a validation period, and again indicate that both models produce results that are similar to the observed trends, with ERHYM being slightly better.

As previously discussed, potential evapotranspiration is determined by different methods in the two models. SPAW uses daily pan evaporation values and monthly coefficients while ERHYM uses the Jensen-Haise method based on daily air temperature and solar radiation values. Figure 7.20 shows the accumulated potential evapotranspiration curves for both models

Table 7.5.--Regression equations and coefficients for calculated versus observed soil moisture on measurement days (approximately two-week intervals).

Site	Year	SPAW Regression Equation	R^2	ERHYM Regression Equation	R^2
Flats	1976	Y = 3.7598 + 0.4431X	.56	Y = 0.2774 + 0.9233X	.91
	1977	Y = 4.2539 + 0.4453X	.36	Y = 1.6259 + 0.7462X	.76
	1978	Y = 0.1251 + 1.0162X	.83	Y = -0.1204 + 0.7462X	.95
	1979	Y = 1.1230 + 1.1351X	.61	Y = -12.1348 + 2.5982X	.91
	1980	Y = 0.2930 + 0.8960X	.83	Y = 2.9982 + 0.6501X	.74
	1976-81	Y = 1.9915 + 0.7065X	.65	Y = -1.1454 + 1.1633X	.84
Lower Sheep					
	1977	Y = 3.9485 + 0.6870X	.71	Y = -2.4110 + 1.2183X	.78
	1978	Y = 3.6543 + 0.7272X	.85	Y = -0.4713 + 1.0376X	.98
	1979	Y = 7.8340 + 0.4091X	.63	Y = -0.7221 + 1.0978X	.91
	1980	Y = 4.8531 + 0.6226X	.80	Y = 4.1008 + 0.7694X	.89
	1981	Y = 3.9179 + 0.6583X	.84	Y = 1.2962 + 0.8899X	.95
	1977-81	Y = 4.6255 + 0.6379X	.79	Y = 0.8645 + 0.9603X	.89

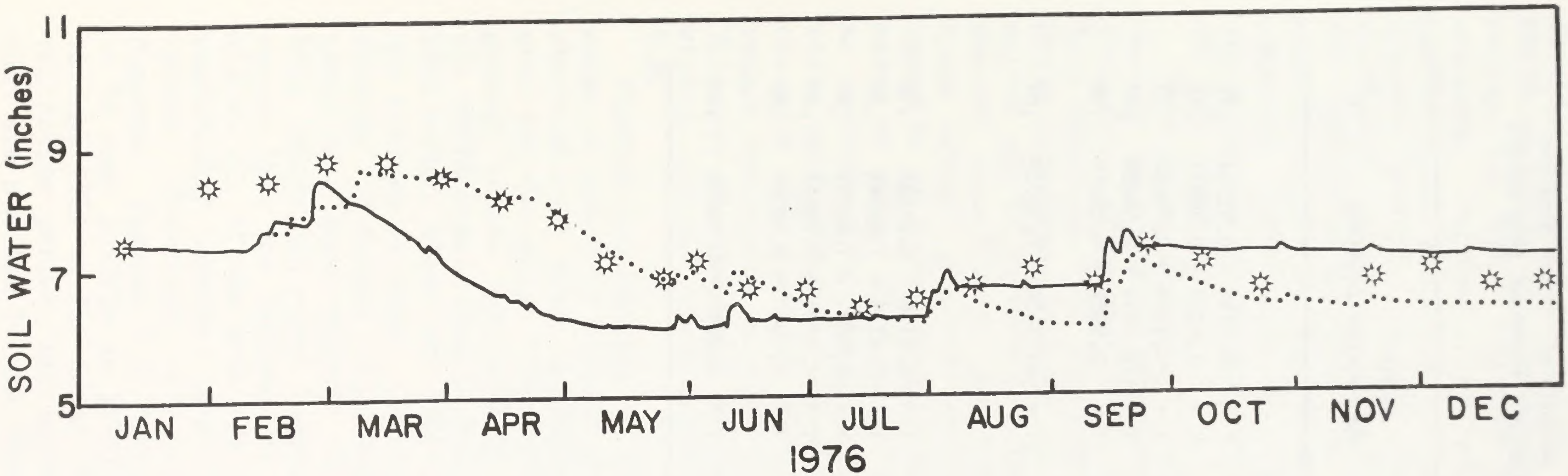


Figure 7.9.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1976 at the Flats site.

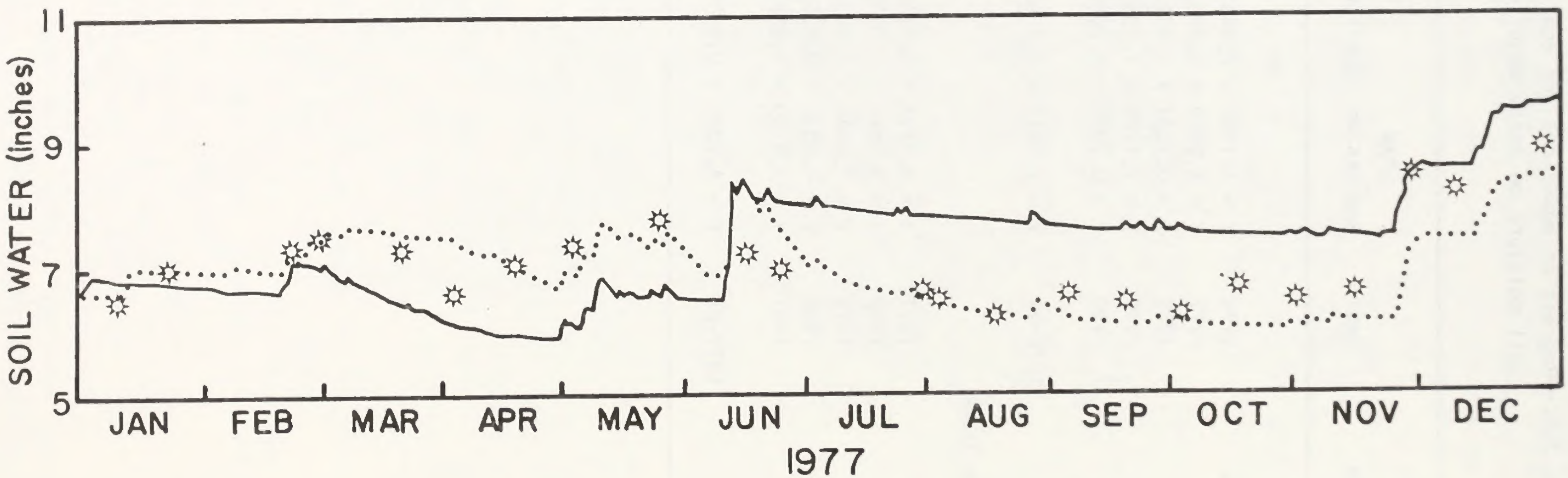


Figure 7.10.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1977 at the Flats site.

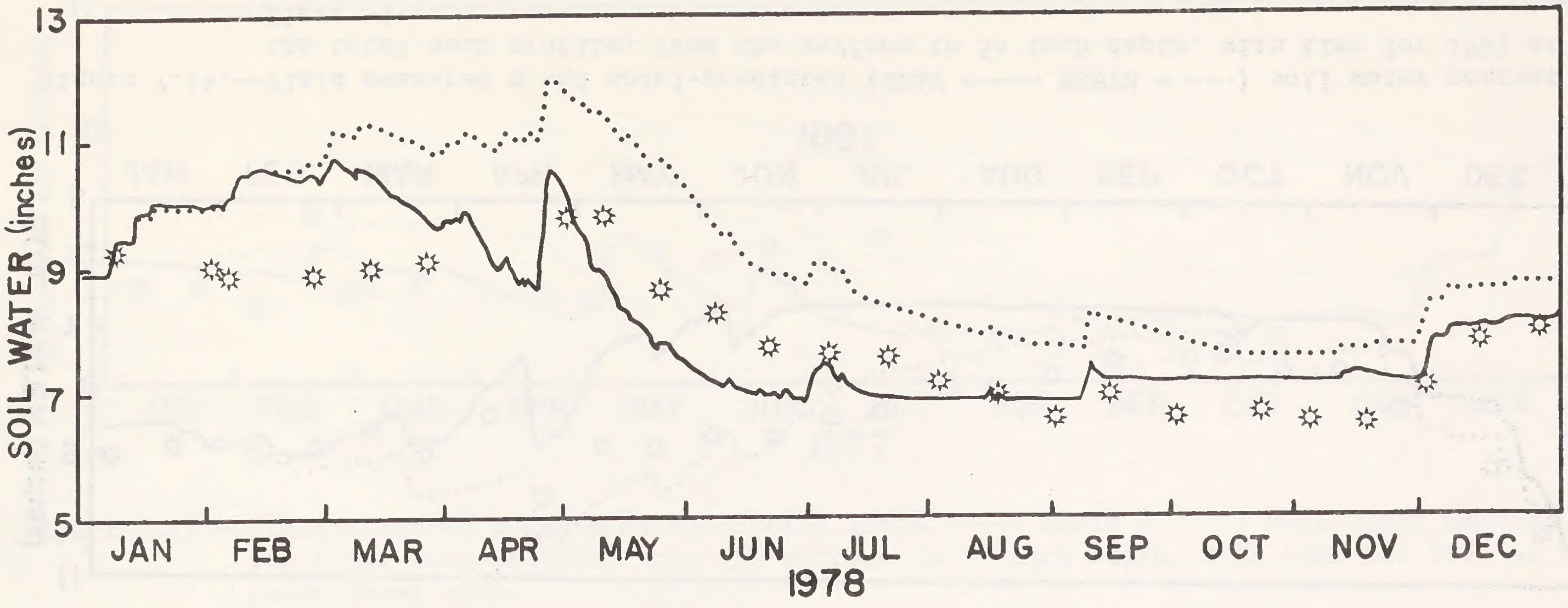


Figure 7.11.--Field measured ☼ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1978 at the Flats site.

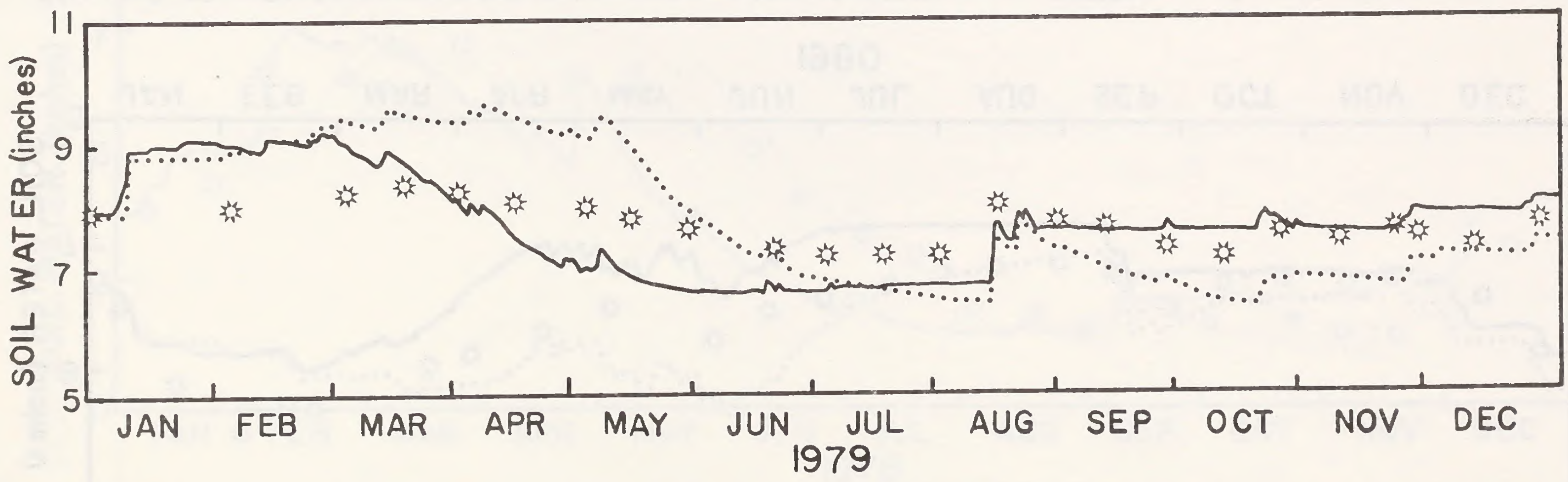


Figure 7.12.--Field measured ☼ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1979 at the Flats site.

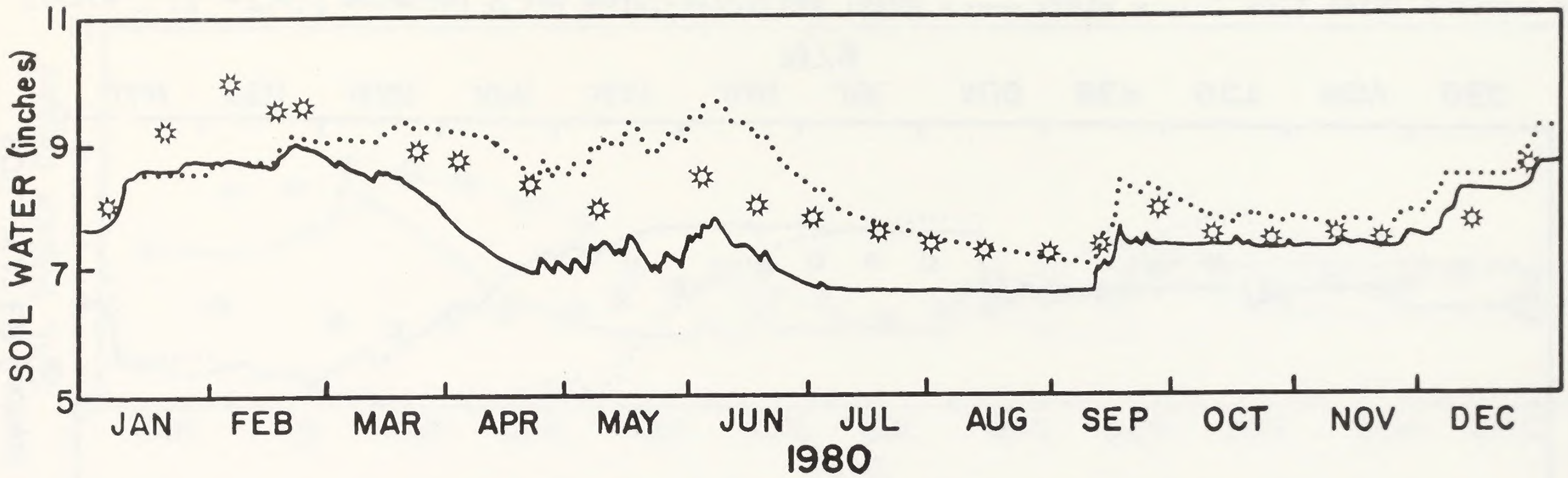


Figure 7.13.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1980 at the Flats site.

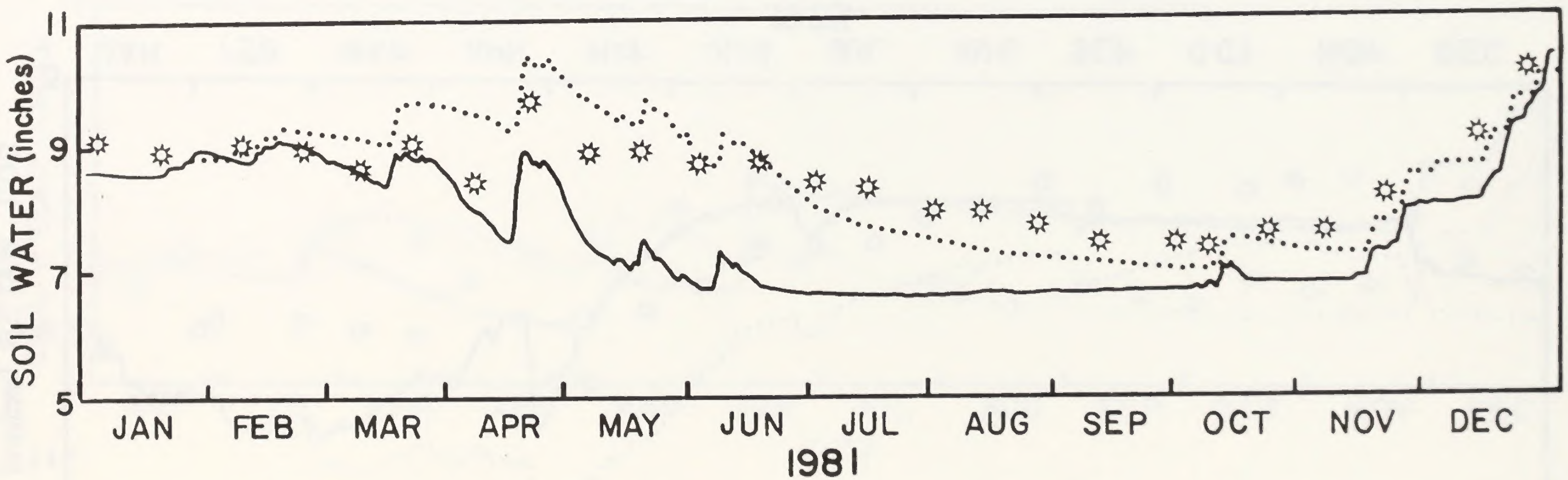


Figure 7.14.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1981 at the Flats site.

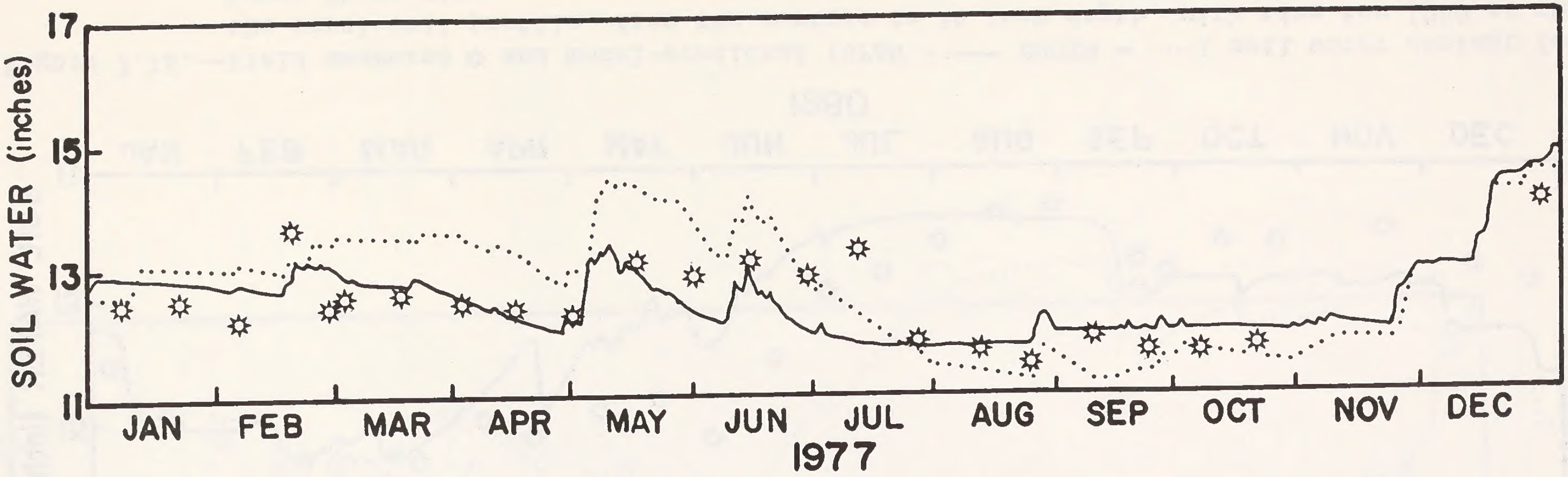


Figure 7.15.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ······) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1977 at the Lower Sheep site.

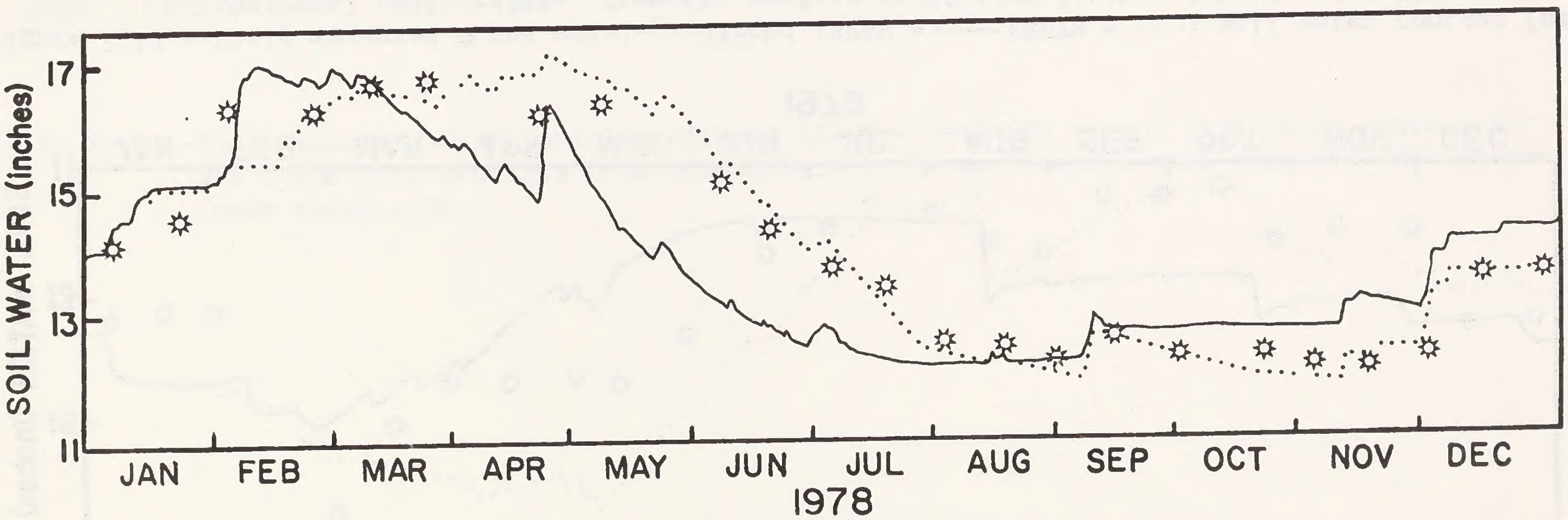


Figure 7.16.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ······) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1978 at the Lower Sheep site.

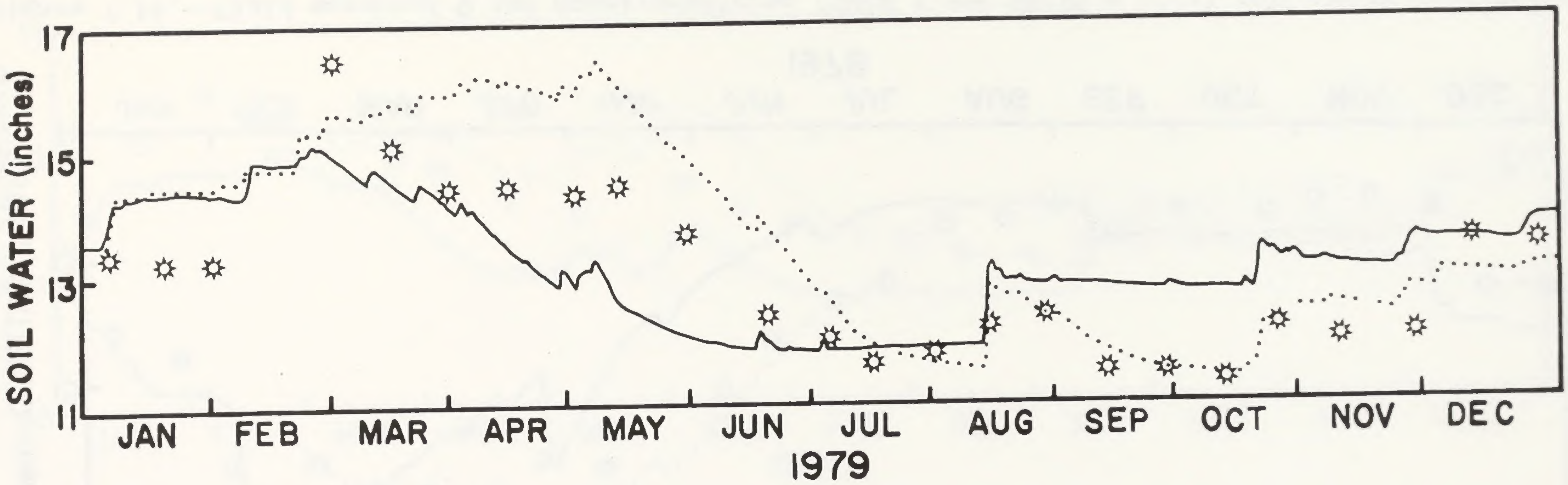


Figure 7.17.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1979 at the Lower Sheep site.

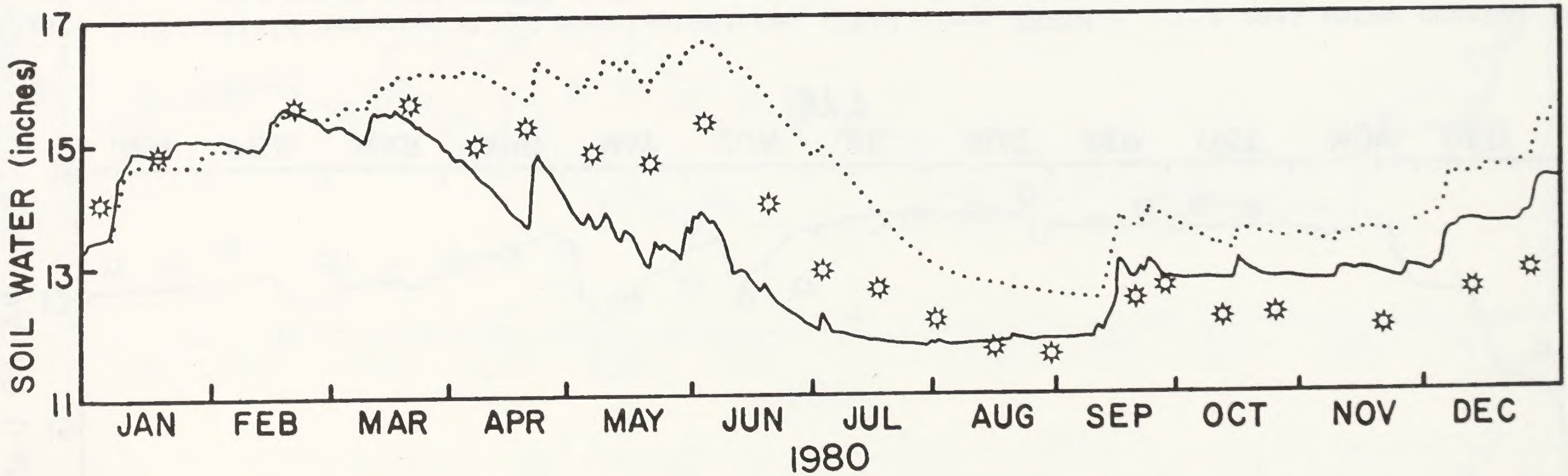


Figure 7.18.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1980 at the Lower Sheep site.

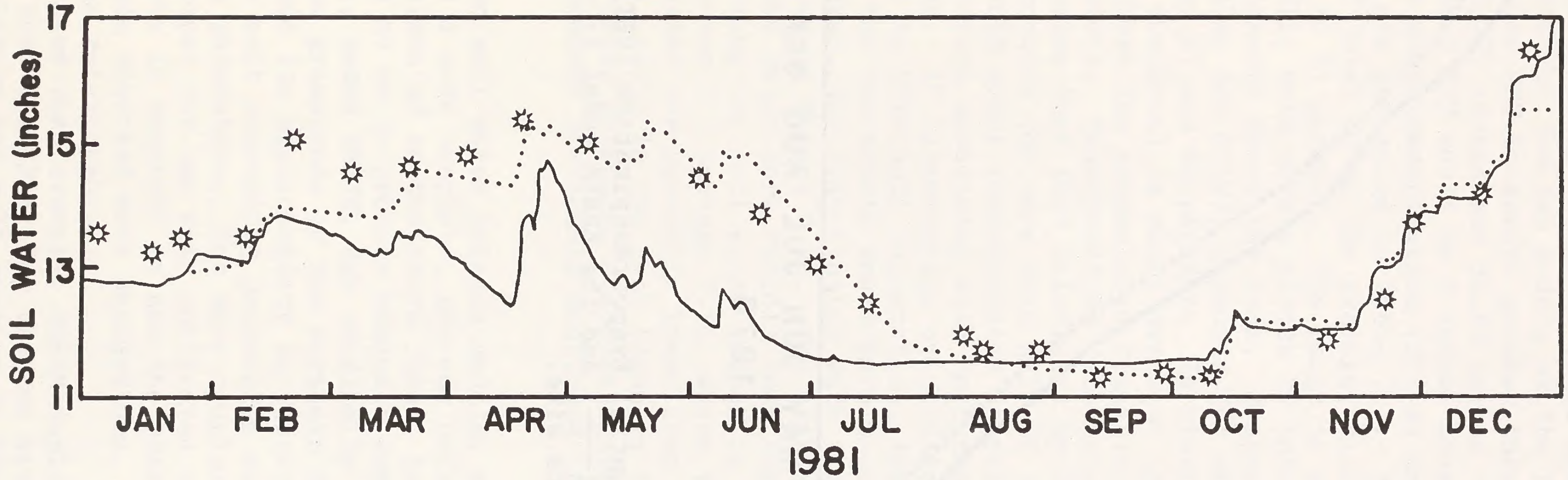


Figure 7.19.--Field measured ✡ and model-predicted (SPAW = —— ERHYM = ·····) soil water content for the total soil profile, from the surface to 54 inch depth, with time for 1981 at the Lower Sheep site.

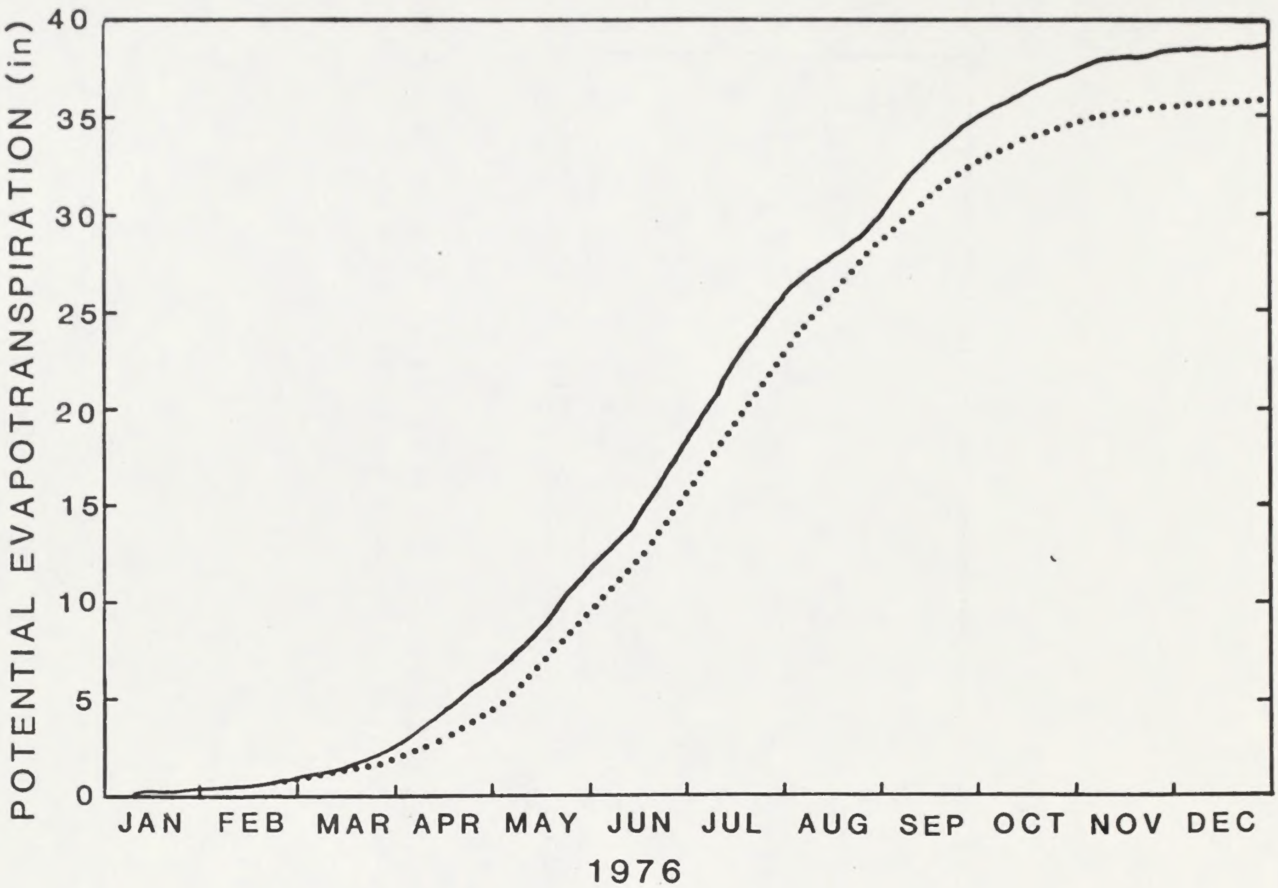


Figure 7.20.--Accumulated Potential Evapotranspiration (PET) as determined by the SPAW model (——) and the ERHYM model (······) with time, for 1976 at the Flats site.

for 1976 at the Flats site. The SPAW model using pan evaporation produces larger values of evapotranspiration than the Jensen-Haise based ERHYM model. Table 7.6 contains values of total accumulated potential evapotranspiration for the two models at the Flats site for 1976 through 1981. SPAW derived PET is always greater than ERHYM produced PET, annual averages being 39.77 inches and 36.68 inches respectively. Thus, on the average, SPAW based PET would be 3 inches more per year than ERHYM based PET. The actual evapotranspiration (ET) at the two sites and their component parts are presented in Table 7.7. Transpiration accounts for 32 to 39 percent of total ET on the average, with values for individual years ranging from 18 to 51 percent. The range is somewhat greater for the SPAW model, but overall, both models divide ET into transpiration and evaporation components about the same. Evaporation from the soil (and plant surfaces also for SPAW), accounts for about two thirds of total ET averaging between 61 and 68 percent. In other words, evaporation from the soil (and plant surfaces) is about twice of that transpired by the plants.

Figure 7.21 shows the accumulated transpiration for 1978 at the Flats site for both models. Transpiration calculated by the SPAW model is considerably greater than that calculated by ERHYM. SPAW model transpiration accounts for more than half of total ET for this relatively wet year, but ERHYM model transpiration is only about one third of total ET. Soil evaporation associated with each model is shown in Figure 7.22 for the same year. If interception evaporation determined in the SPAW model were added to SPAW soil evaporation, the total accumulated evaporation for the two models would have been about the same, as shown in Table 7.5. However, the distribution with time would still be slightly different as shown in Figure 7.22. The SPAW model tends to use (transpire and evaporate) the water more rapidly than does ERHYM (Figure 7.21 and 7.22), thus removing the soil water sooner in the year. This is also indicated in Figures 7.3 through 7.19, where the SPAW model predicted values of soil water are generally lower than observed values, or ERHYM predicted values, early in the year (January to April). This may be a result of the greater potential evapotranspiration determined using pan evaporation procedures previously mentioned (Figure 7.20).

Summary

Testing of two soil water balance models, representing a relatively simple model and a more complete, process oriented, complex model, on rangeland conditions of southwestern Idaho, indicated that both models could be adapted so as to produce adequate results for many applications. The simple model, named ERHYM, was originally developed for use during the growing season on grasslands of the northern Great Plains. It had been modified to extend its applicability to year-round use and to include snow accumulation and melt accounting procedures and more user-oriented soil and plant growth parameters. The more complex model, named SPAW, was originally developed for use with cultivated crops in the Midwest. Somewhat more data is required to use the SPAW model, and adaptation to western rangelands required more assumptions, particularly in the plant growth and stress relationships.

Results indicated that overall, ERHYM duplicated observed values slightly better than did SPAW, for the two sites investigated. The lack of a snow accumulation and melt routine in SPAW may be the main source of error in this case. This error is more a function of timing than a

Table 7.6.--Potential evapotranspiration (PET) as calculated by the SPAW and ERHYM models for the years 1976-1981, at the Flats (in inches).

Year	SPAW PET	ERHYM PET
1976	38.45	35.98
1977	40.60	36.34
1978	39.57	38.00
1979	43.17	36.20
1980	37.48	35.91
1981	39.32	37.66
Avg.	39.77	36.68

Table 7.7.--Annual values of actual evapotranspiration, transpiration, and evaporation in inches as determined by SPAW and ERHYM for the Flats and Lower Sheep sites. Also ratios of transpiration and evaporation to actual evapotranspiration.

		ERHYM					SPAW					
		T	T/ET	E	E/ET	ET	T	T/ET	E*	E/ET	ET	Precipitation
Flats	1976	1.61	.22	5.73	.78	7.34	2.23	.33	4.58	.67	6.81	6.78
	1977	2.04	.25	6.14	.75	8.18	1.30	.18	5.74	.82	7.04	10.17
	1978	3.66	.38	5.99	.62	9.65	5.87	.51	5.59	.49	11.47	10.51
	1979	2.71	.32	5.77	.68	8.48	2.60	.32	5.60	.68	8.20	8.00
	1980	3.42	.35	6.36	.65	9.78	4.07	.38	6.66	.62	10.73	11.22
	1981	3.14	.39	4.85	.61	7.99	4.76	.51	4.59	.49	9.35	10.73
Totals and Averages		16.58	.32	34.84	.68	51.42	20.83	.39	32.76	.61	53.59	57.41 (9.57)**
Lower Sheep	1976	4.31	.38	6.93	.62	11.24	--	--	--	--	--	9.45
	1977	3.05	.33	6.27	.67	9.32	3.08	.32	6.62	.68	9.70	11.47
	1978	4.17	.40	6.34	.60	10.51	5.03	.39	7.84	.61	12.87	13.49
	1979	3.86	.38	6.22	.62	10.08	2.82	.28	7.21	.72	10.04	10.37
	1980	4.28	.38	7.04	.62	11.32	5.31	.38	8.64	.62	13.96	15.11
	1981	3.51	.40	5.35	.60	8.86	4.72	.42	6.46	.58	11.16	15.55
Totals and Averages		23.18	.38	38.15	.62	61.33	20.96	.36	36.77	.64	57.73	75.44 (12.57)**

*Includes soil evaporation plus interception evaporation.
**Average precipitation for 6-year study period.

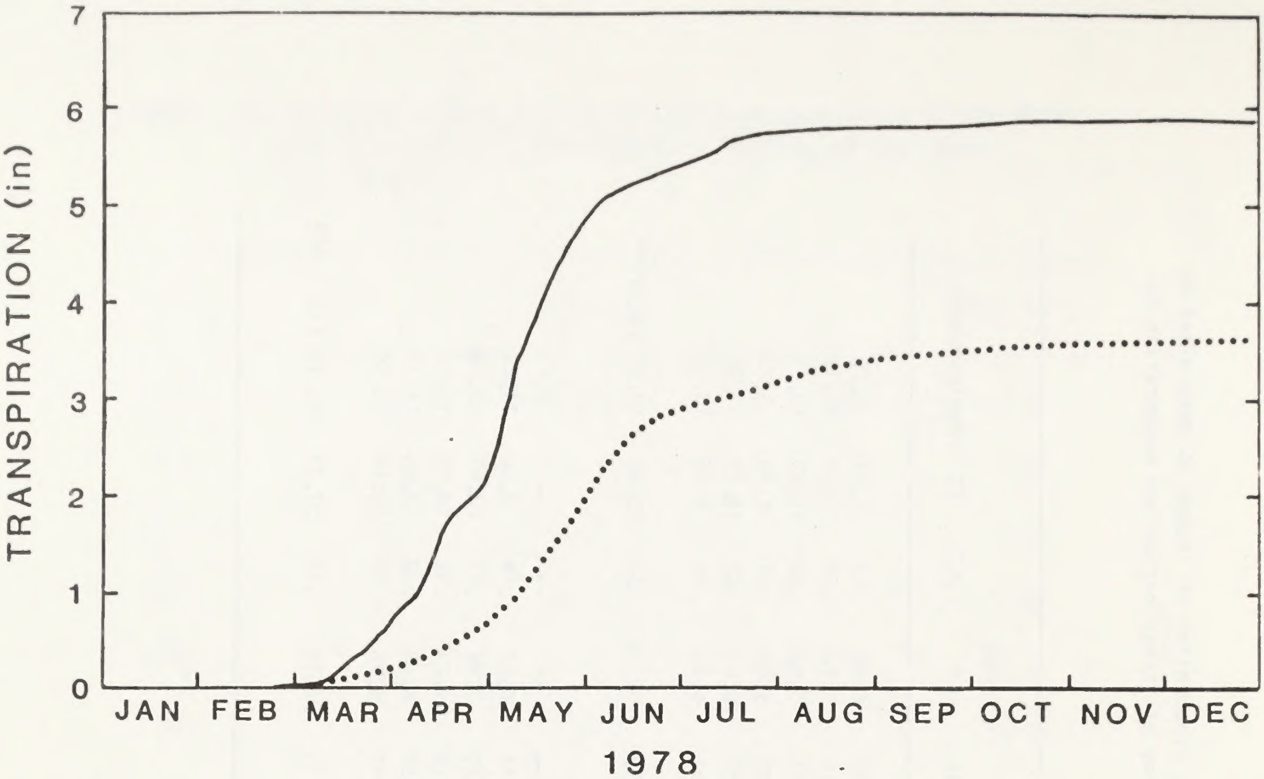


Figure 7.21.--Accumulated Transpiration as determined by the SPAW model (——) and the ERHYM model (······) with time, for 1978 at the Flats site.

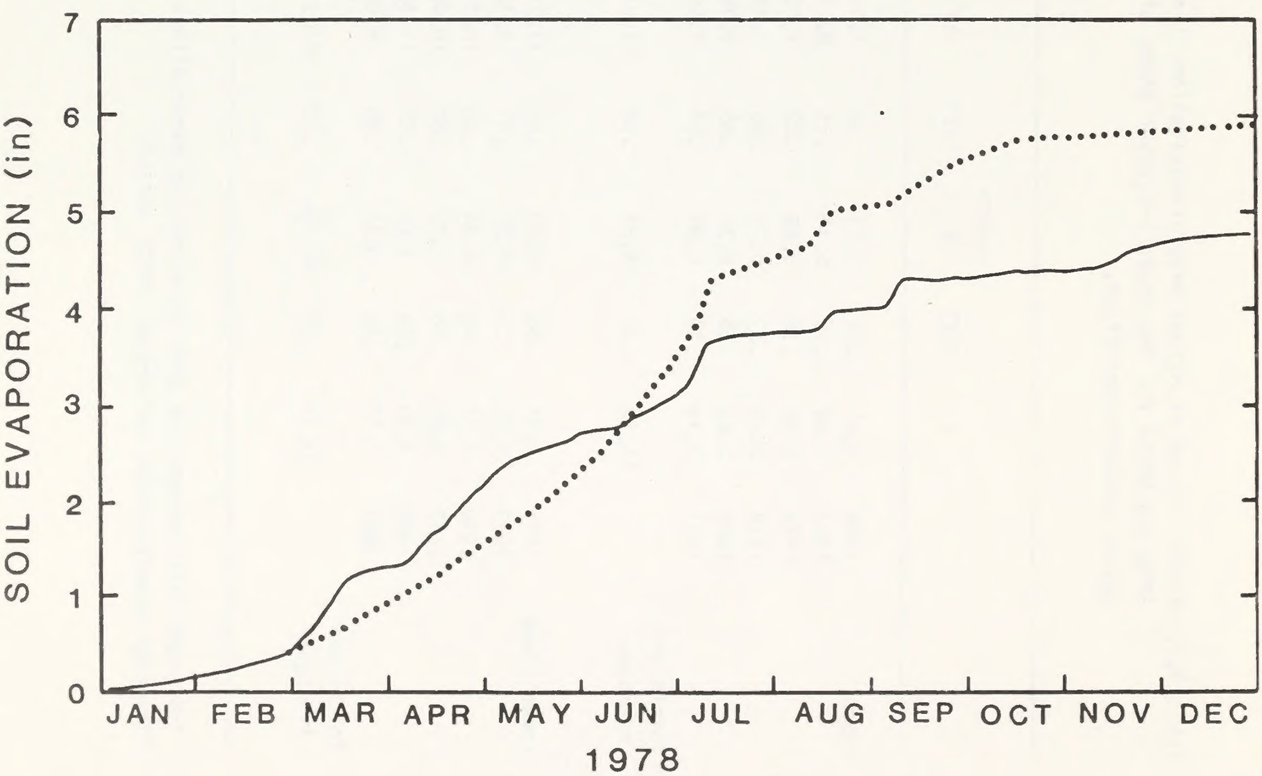


Figure 7.22.--Accumulated soil evaporation as determined by the SPAW model (——) and the ERHYM model (······) with time, for 1978 at the Flats site. (Interception evaporation used in SPAW model was not included.)

difference in total soil water at the end of the year, where results for the two models were very similar.

The ability to predict soil water as a function of time and depth, through the use of models such as SPAW and ERHYM, could be a great help to managers considering range improvements such as plowing, ripping, reseeding, vegetation manipulation, prescribed burning, and other range practices. The use of these models to forecast possible soil water scenarios would also be very useful in predicting possible forage production and the associated stocking rates.

Conclusions reached in this evaluation of the two soil water balance models can be summarized as follows:

Both models were adaptable to western rangeland conditions and produced results which followed observed trends adequately. The ERHYM model would probably produce better, or more economical, results if: 1) snowfall occurred during the study period that would cause temporary storage of significant amounts of precipitation on the surface; 2) plant growth and stress data are not available for the species under investigation; and 3) computer capacity is limited, or cost of computer operation is significant.

PRODUCTIVITY MODEL

Modification and Evaluation of ERHYM

ERHYM (Ekalaka Rangeland Hydrology and Yield Model) (Wight and Neff 1983) is a physically-based climate, water-balance model developed to predict annual herbage yield and runoff from northern Great Plains rangelands. Because of its mechanistic nature, it should be applicable to a wide range of grassland ecosystems, provided the input parameters are adequately defined. As initially developed, ERHYM utilizes a single set of soil temperature curves to represent various soil depths in the northern great plains. Also, the crop coefficients (CROPCO) and transpiration coefficients (TRANCO) were based on the vegetation characteristics of the mixed-grass prairie. The purpose of this study was to modify and evaluate ERHYM for application to sagebrush-grass ecosystems using data from the Reynolds Creek Experimental Watershed.

Soil temperature data from the lower elevation sites at Reynolds Creek indicated that soil temperature may not be the critical factor that it was in the northern Great Plains where subsurface soil layers often remained at subfreezing temperatures late into May. However, a soil temperature submodel from EPIC (Erosion Productivity Impact Calculator) was interfaced to ERHYM and evaluated. Preliminary results (Figures 7.23a-7.23d) indicated a reasonable relationship between field-measured and model-predicted soil temperatures. Average mean monthly air temperatures are the only additional input parameters needed.

The soil water characteristics of the soil profile (permanent wilting, field capacity, and beginning soil water content) are usually determined gravimetrically on soil samples that exclude the rock fragment of the profile. To account for the rock content of the soil as it affects the volumetric soil water holding characteristics, a rock factor was added to the model. For each soil layer, the volumetric water content is multiplied by the rock factor (1-[% rock/100]) for that layer.

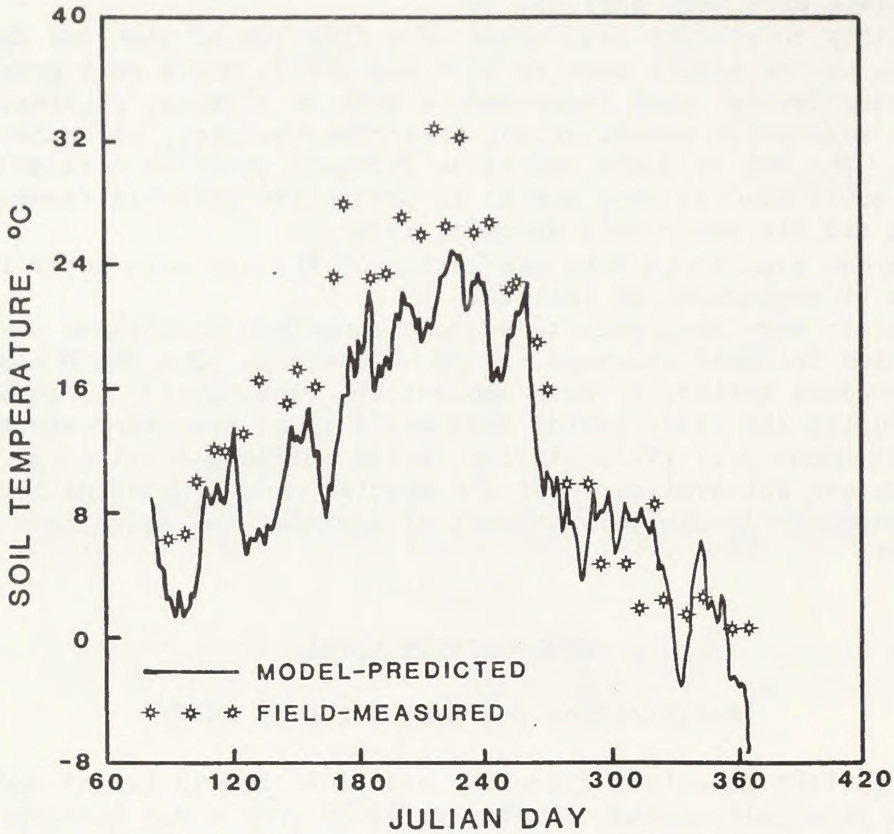


Figure 7.23a.--Comparison of model-predicted and field-measured soil temperatures for the four-inch depth, Reynolds Creek, 1981.

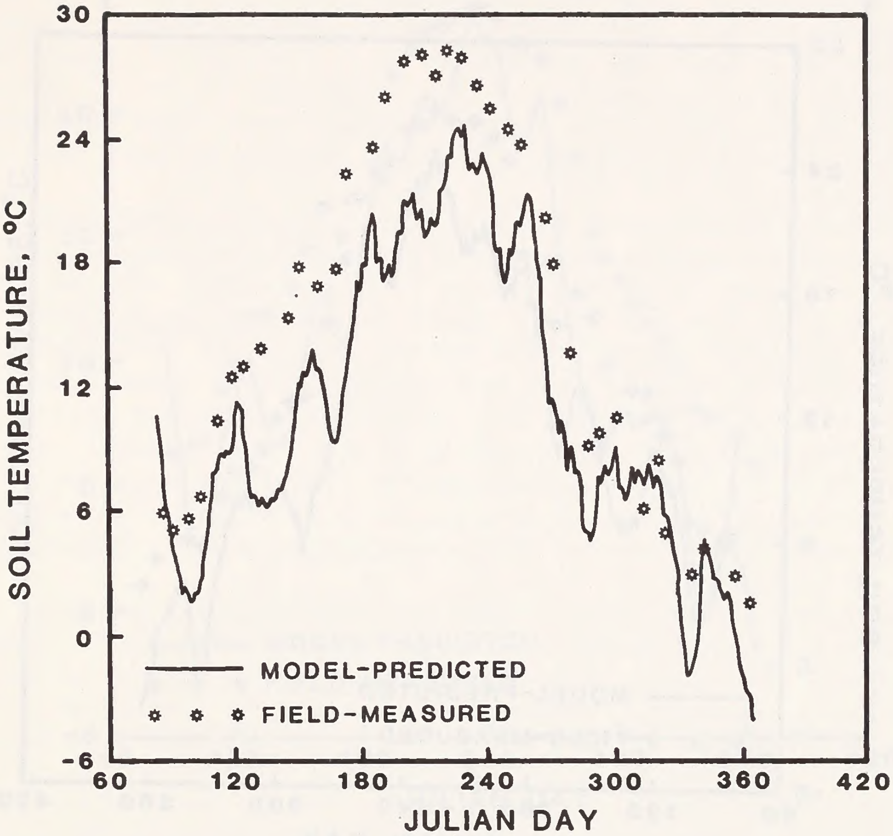


Figure 7.23b.--Comparison of model-predicted and field-measured soil temperatures for the 12-inch depth, Reynolds Creek, 1981.

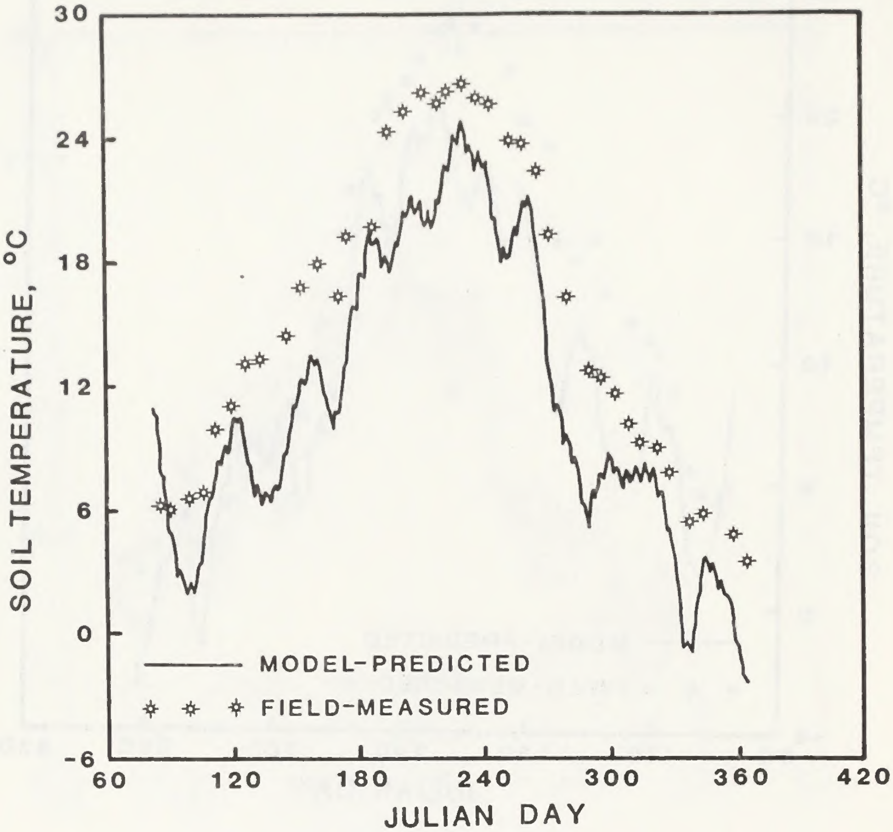


Figure 7.23c.--Comparison of model-predicted and field-measured soil temperatures for the 24-inch depth, Reynolds Creek, 1981.

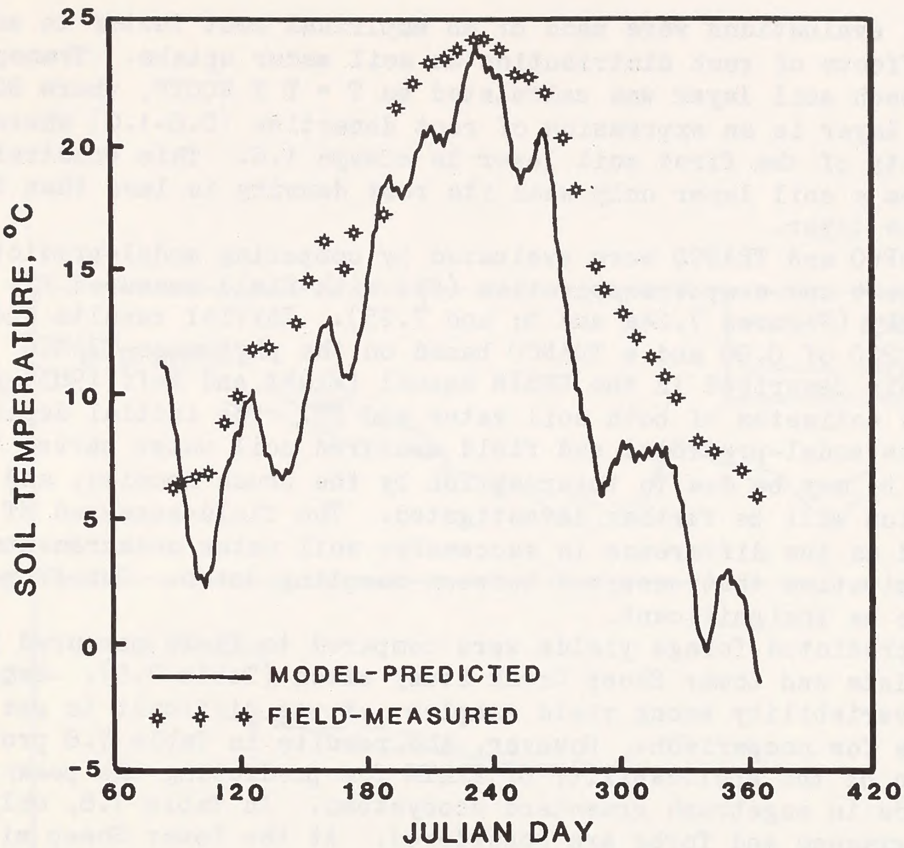


Figure 7.23d.--Comparison of model-predicted and field-measured soil temperatures for the 36-inch depth, Reynolds Creek, 1981.

Initial evaluations were made of an empirical root factor to account for the effects of root distribution on soil water uptake. Transpiration (T) from each soil layer was calculated as T = T X ROOTF, where ROOTF for each soil layer is an expression of root densities (0.0-1.0) where the root density of the first soil layer is always 1.0. This constrains water uptake from a soil layer only when its root density is less than that of the surface layer.

The CROPCO and TRANCO were evaluated by comparing model-predicted soil water content and evapotranspiration (ET) with field-measured ET, respectively (Figures 7.24a and b; and 7.25). Initial results indicated that a CROPCO of 0.80 and a TRANCO based on the phytomass-TRANCO relationship described in the ERHYM manual (Wight and Neff 1983) provided reasonable estimates of both soil water and ET. The initial departure between the model-predicted and field measured soil water curves (Figure 7.24a and b) may be due to interception by the brush species, and interception will be further investigated. The field-measured ET was calculated as the difference in successive soil water measurements, plus the precipitation that occurred between sampling dates. Runoff was assumed to be insignificant.

Model-predicted forage yields were compared to field measured yields for the Flats and Lower Sheep Creek study sites (Table 7.8). Because of the high variability among yield samples, it was difficult to get reliable yield data for comparison. However, the results in Table 7.8 provide an indication of the applicability of ERHYM for predicting the peak standing crop yields in sagebrush grassland ecosystems. In Table 7.8, only the yield of grasses and forbs are considered. At the Lower Sheep site there was reasonably good agreement between model-predicted and field-measured yields. The drought in 1977 was well represented by the model. At the Flats site, the model did not perform as well. It has no mechanism to account for influxes of annual cheatgrass that occur at the Flats site but not at the Lower Sheep site. Fall growing conditions play a major role in the yield fluctuations of this annual, and the model as it currently functions does not consider the previous fall conditions. It appears that some modifications may be necessary before the model can effectively predict yields on range sites dominated by annual grasses.

The evaluation of ERHYM for sagebrush-grassland range sites has been somewhat brief but the results to date indicate that it can be an effective tool for estimating soil water, ET, and herbage yields on these sites. Development and evaluation of ERHYM will continue.

Users Manual for ERHYM

At this point, the description of the model operation in ERHYM (Wight and Neff 1983) is entirely adequate; a two or three line modification of the input format is all that is needed. As the modification and evaluation of ERHYM are completed, a detailed user manual will supplement the ERHYM publication (Wight and Neff 1983). The user manual will describe in detail the model inputs and outputs, and will have appropriate tables and examples so that the model can be run with a minimum amount of pretraining. The ERHYM model will soon be available in the BASIC computer language for operation on personal type computers.

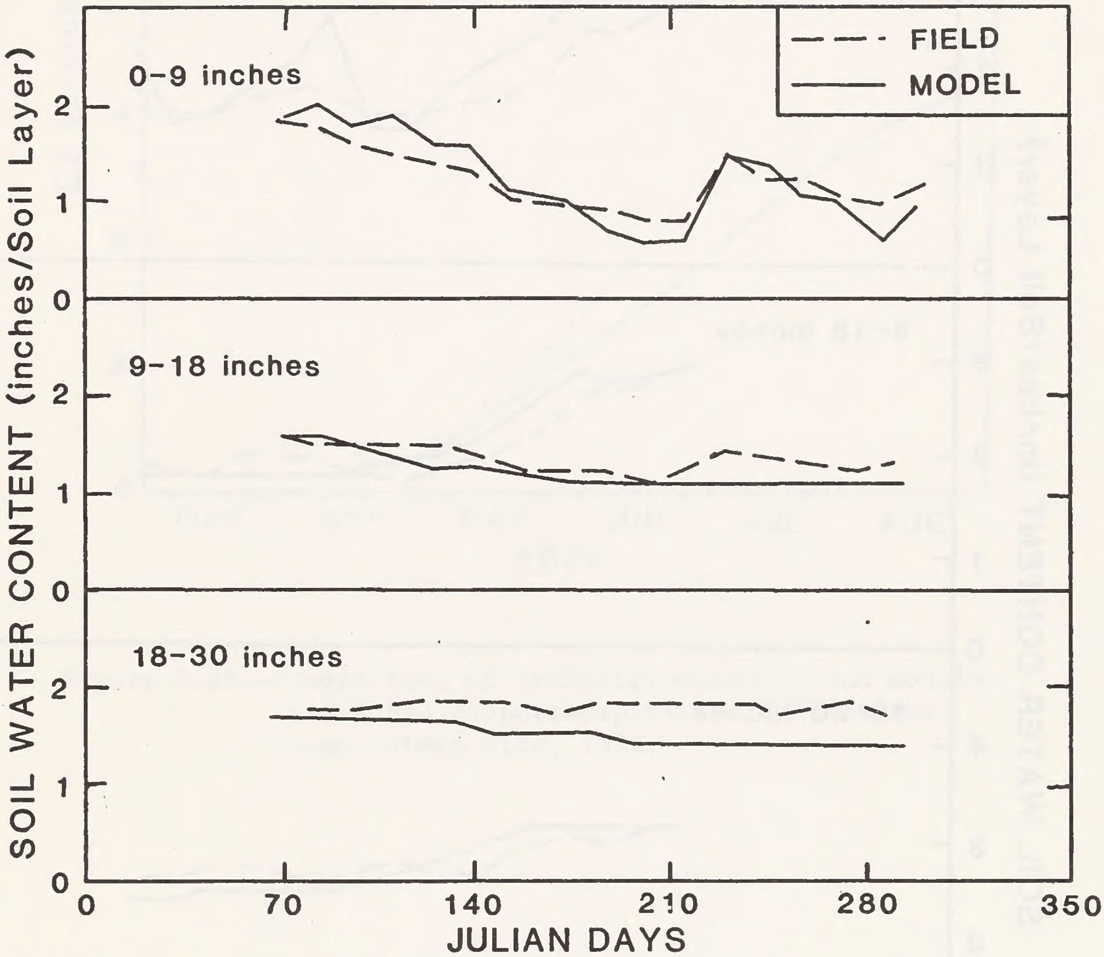


Figure 7.24a.--Comparison of model-predicted and field-measured soil water contents, Flats site, 1979.

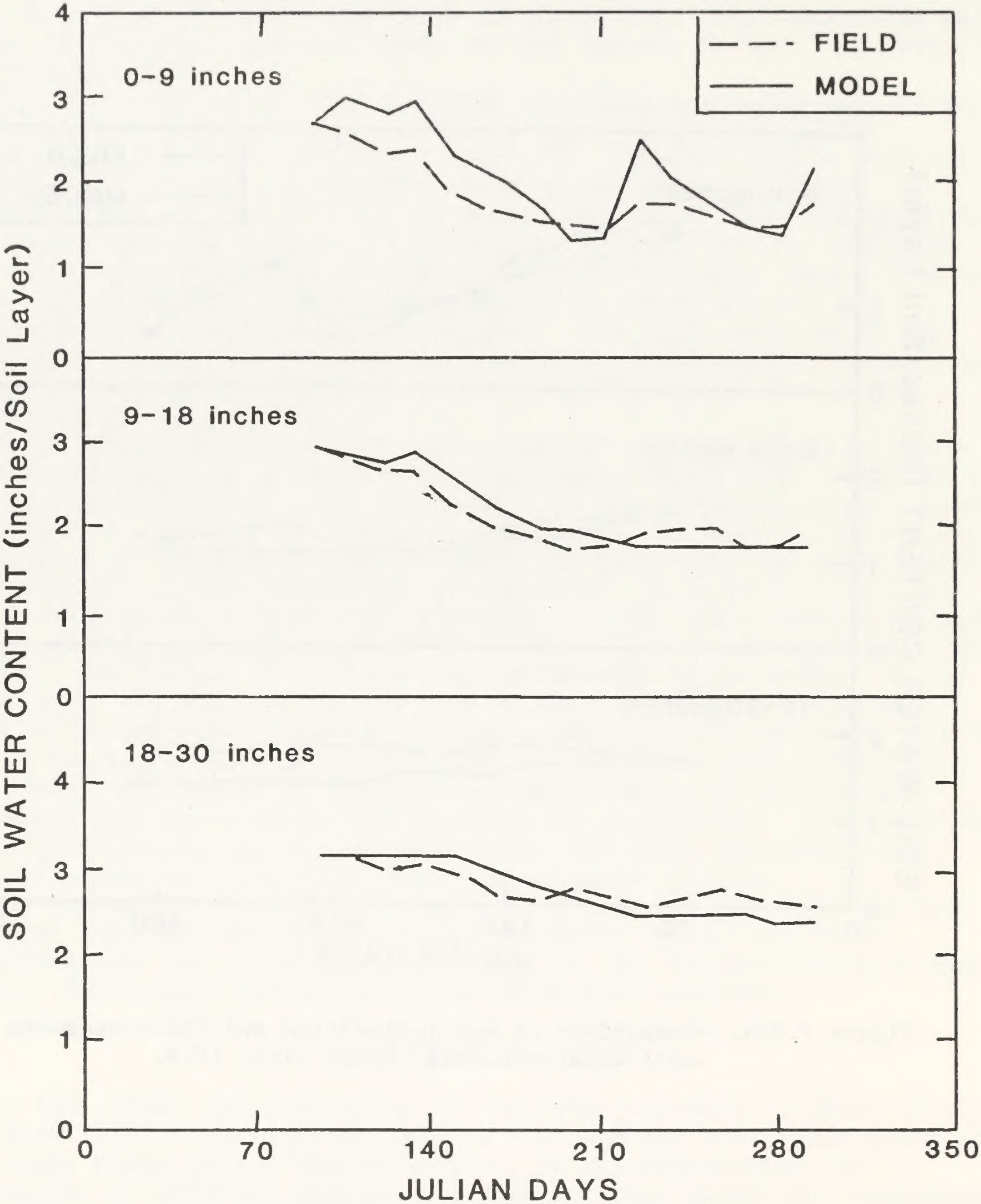


Figure 7.24b.--Comparison of model-predicted and field-measured soil water contents, Lower Sheep site, 1979.

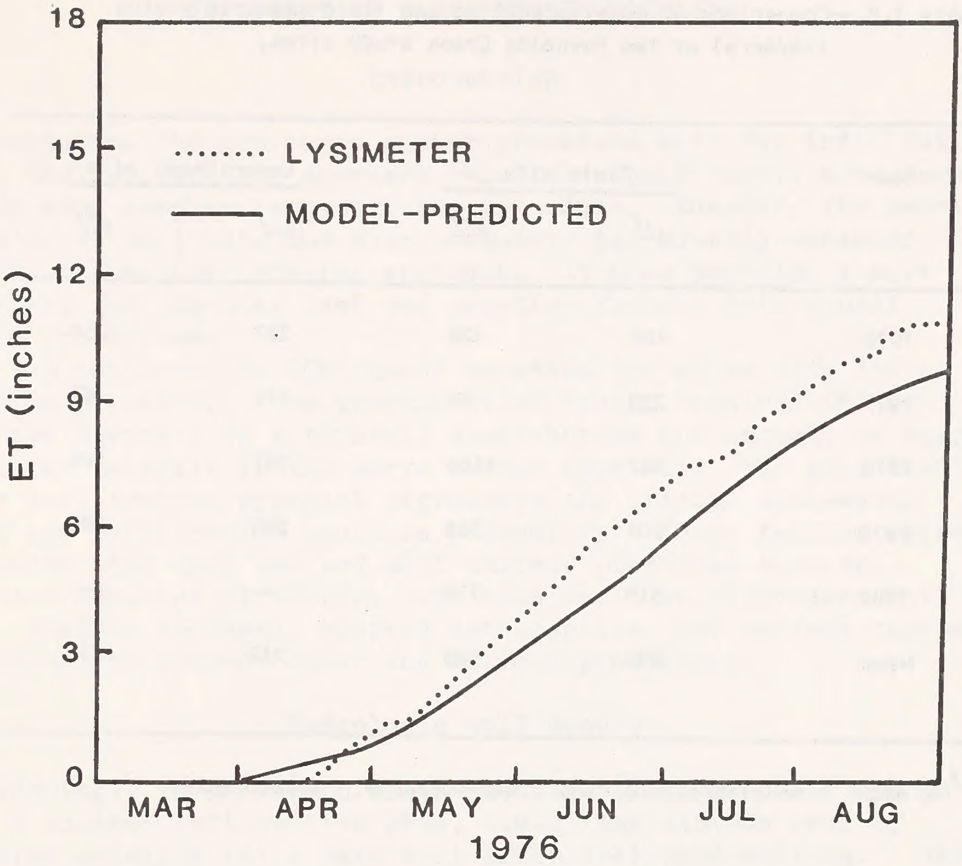


Figure 7.25.--Comparison of lysimeter-measured and model-predicted evapotranspiration (ET) at the Lower Sheep site, 1976.

Table 7.8.--Comparison of model-predicted and field-measured yields (lb/acre) at two Reynolds Creek study sites.

Year	Flats site		Lower Sheep site	
	M[1/]	F[1/]	M[1/]	F[1/]
1976	488	428	287	234
1977	220	96	112	67
1978	542	1165	287	346
1979	504	333	281	280
1980	515	776	---	---
Mean	454	560	242	231

[1/] M and F = model-predicted and field-measured, respectively.

INFILTRATION BASED RUNOFF MODELING

Introduction

When comparing the SCS curve number procedure with the infiltration approach, the infiltration approach requires significantly more input data and a much more complex computational procedure. However, the general availability of soil data and microcomputers has greatly enhanced the feasibility of the infiltration approach. It also provides a more objective way for inputing land use practice factors into runoff prediction procedures.

Table 7.9 compares the SCS runoff equation procedure with the infiltration procedure. The precipitation factor required in the infiltration approach is a rainfall distribution and amount, as compared to just total rainfall in the curve number approach. The soil factor under the infiltration approach represents the initial soil-water condition and infiltration equation parameters. Cover factors represent the influence that land use and soil surface practices have on infiltration equation parameters, and also includes antecedent soil water content. Surface storages, surface interception, and surface depressions, are determined by surface cover and surface practices.

Hydrologic Soil Groups

The hydrologic parameter on which the SCS hydrologic soil groups are based is a minimum infiltration rate, i.e., "the minimum rate of infiltration obtained for a bare soil after prolonged wetting." The original SCS soil listing was based on rainfall-runoff data from small watersheds or infiltrometer plots. However, much of the present soil list is based on comparisons of soils with those soils already hydrologically classified. The classifications are based on the premise that similar soils (similar in depth, organic-matter content, structure, and degree of swelling when saturated) will respond in an essentially similar manner during a rain storm having excessive intensities.

Four soil groups, A, B, C, and D, were defined with numerical limits for conductivity established by Musgrave (1955). We have assumed that the conductivity parameter, K, of the Green and Ampt infiltration equation, which is approached after prolonged wetting, corresponds to the minimum infiltration rate used in the SCS classification of soils. The Green and Ampt equation is

$$f = K\left(1 + \frac{\psi_f n}{F}\right) \qquad [7.1]$$

in which K is conductivity parameter; ψ_f is soil capillary suction parameter; n is available soil porosity; f is rate; and F is accumulated amount. K is one-half of the saturated conductivity, K_s.

Figure 7.26 presents soil texture triangles upon which the numerical limits for K have been used to delineate the hydrologic soils groups. These charts are adapted from research on predicting Green and Ampt parameters from soil texture, organic matter content, and soil porosity

Table 7.9.--Comparison of curve number and infiltration runoff prediction approaches.

Factors	Curve Number[1/]	Infiltration
Precipitation:	Rainfall amount (24-hr)	Rainfall intensities or rainfall distribution and amount
Soil:	Antecedent Moisture Condition (I, II, or III)	Antecedent soil-water storage (volume) by soil layers or soil depth
	Hydrologic Soil Group (HSG) (A, B, C, or D)	Soil-water propertes by layers or soil depth, i.e., bulk density, saturated conductivity, and soil-water entry or bubbling pressure
Cover:	Land use Treatment or Practice Hydrologic condition	Tillage influences on soil properties Land use and treatment, practices' influences on soil properties Ground cover (live or mulch), influences on surface soil properties
Storage:		
Soil	Initial abstraction (I_a), assumed as 0.2 (S)	Total infiltration prior to surface ponding
Surface	Included with initial abstraction, I_a	Estimated soil surface storage as influenced by topography, land use, and tillage
Interception	Included with initial abstraction I_a	Estimated interception storage by ground cover (live and/or mulch)

1/ The factors under the Curve Number Approach are taken from Table 9.1 and Figure 10.1, SCS National Engineering Handbook, Section 4 - Hydrology.

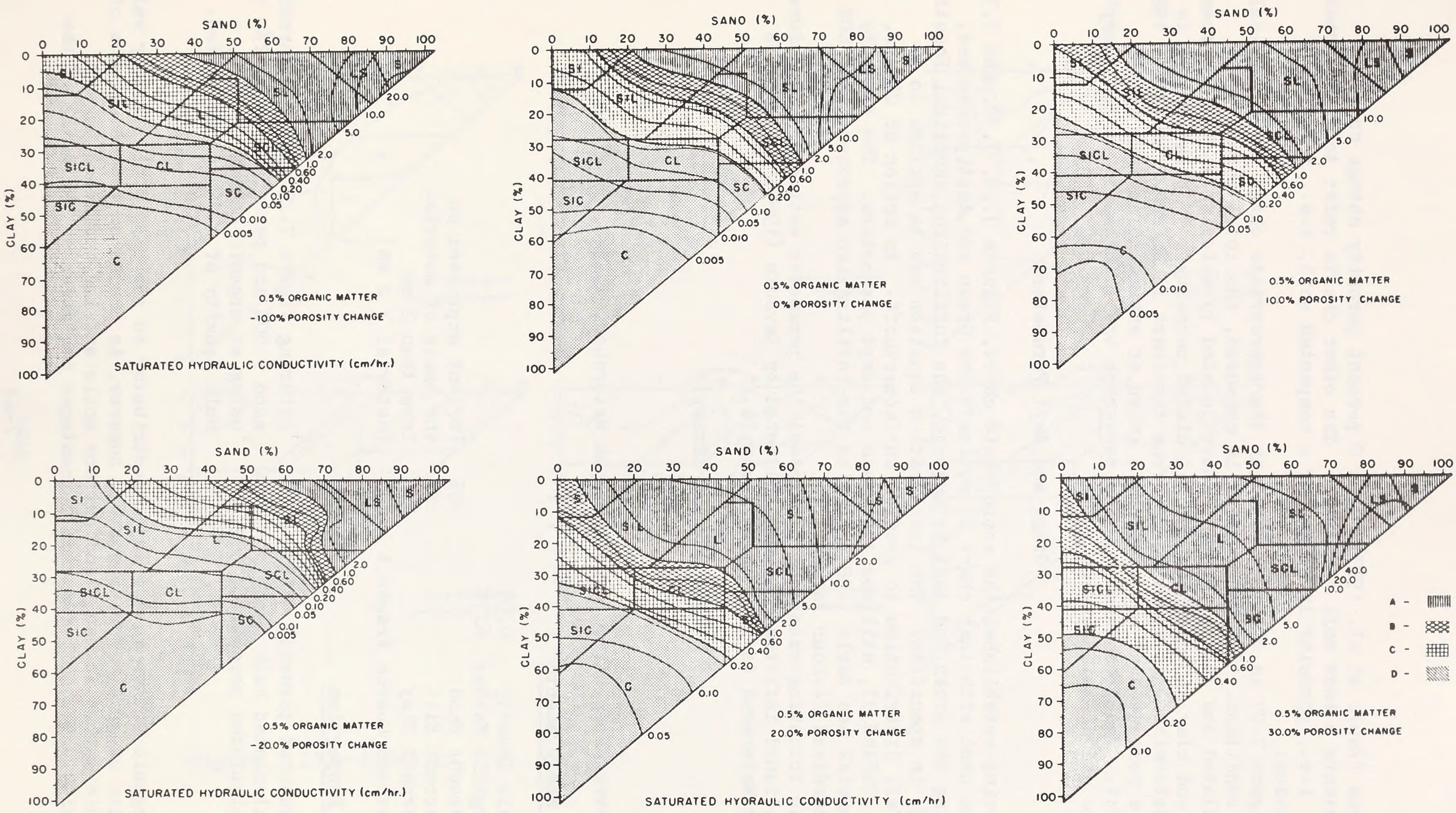


Figure 7.26.--SCS Hydrologic Soil Groups.

changes (Rawls et al. 1983). The 0 percent porosity change chart represents a base soil condition. The other charts refer to a disturbed soil, i.e., porosity increases or a compacted soil, i.e., porosity decreases.

Figure 7.27 is used to establish the appropriate chart for a particular soil condition. If bulk density is measured, the total porosity is calculated and the appropriate chart located by entering with the percent sand and clay and matching the calculated porosity. If bulk density is not determined, it is estimated from the chart in Figure 7.28 (Rawls 1983) with a percent sand and clay and a known or estimated organic matter content. The procedures in this paragraph are illustrated in the example at the end of this section.

Green and Ampt Parameters

Having established the appropriate chart, Figures 7.29, 7.30, and 7.31 can be used with that chart to estimate the Green and Ampt parameters. Knowing the Green and Ampt parameters, the infiltration equation, Equation [7.1], is specified. The infiltration equation can be applied to a rainfall distribution to predict surface runoff. An option of CREAMS, i.e., CREAMS II, utilizes the Green and Ampt parameters. The paper by Brakensiek and Rawls (1982) applied the infiltration approach to an SCS standardized 24-hour rainfall.

The following example will present the parameter estimation procedure. Unpublished infiltration data collected by Devaurs (1983) on Reynolds Creek Watershed is used in the example.

Example

Site

Lower Sheep site, Reynolds Creek Watershed, Grazed, 9% slope

Soil Measurements

Bulk Density	0.95		
Organic Matter	6.7%		
Percent Sand		60%	Percent expressed on
Percent Silt		28%	the basis of material
Percent Clay		12%	less than 2 mm
Percent Coarse Fragment		20%	(material > 2 mm)

Soil Properties

Measured porosity = 64%
Calculated bulk density = 1.10
Calculated porosity = 58%

Entering Figure 7.28 with the percent sand = 60% and percent clay = 12%, and using an organic matter of 6.7%, a bulk density of 1.10 is calculated.

Organic matter is the major contributor to the high soil porosity value of this example. More research, however, is needed on the occurrence of organic matter in rangeland surface soils and its influence on soil porosity. The soil fraction percentages are given on the basis of the

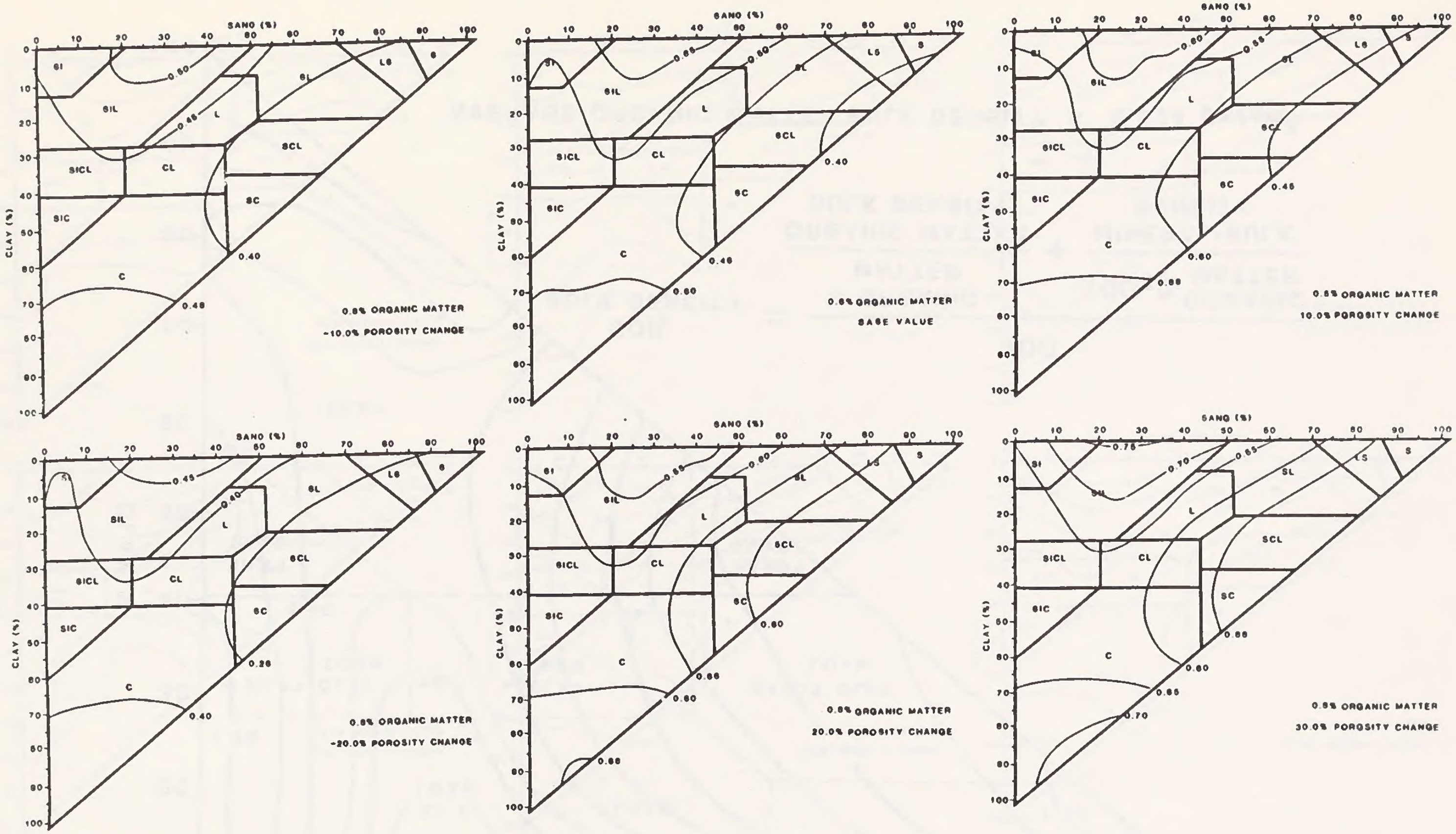
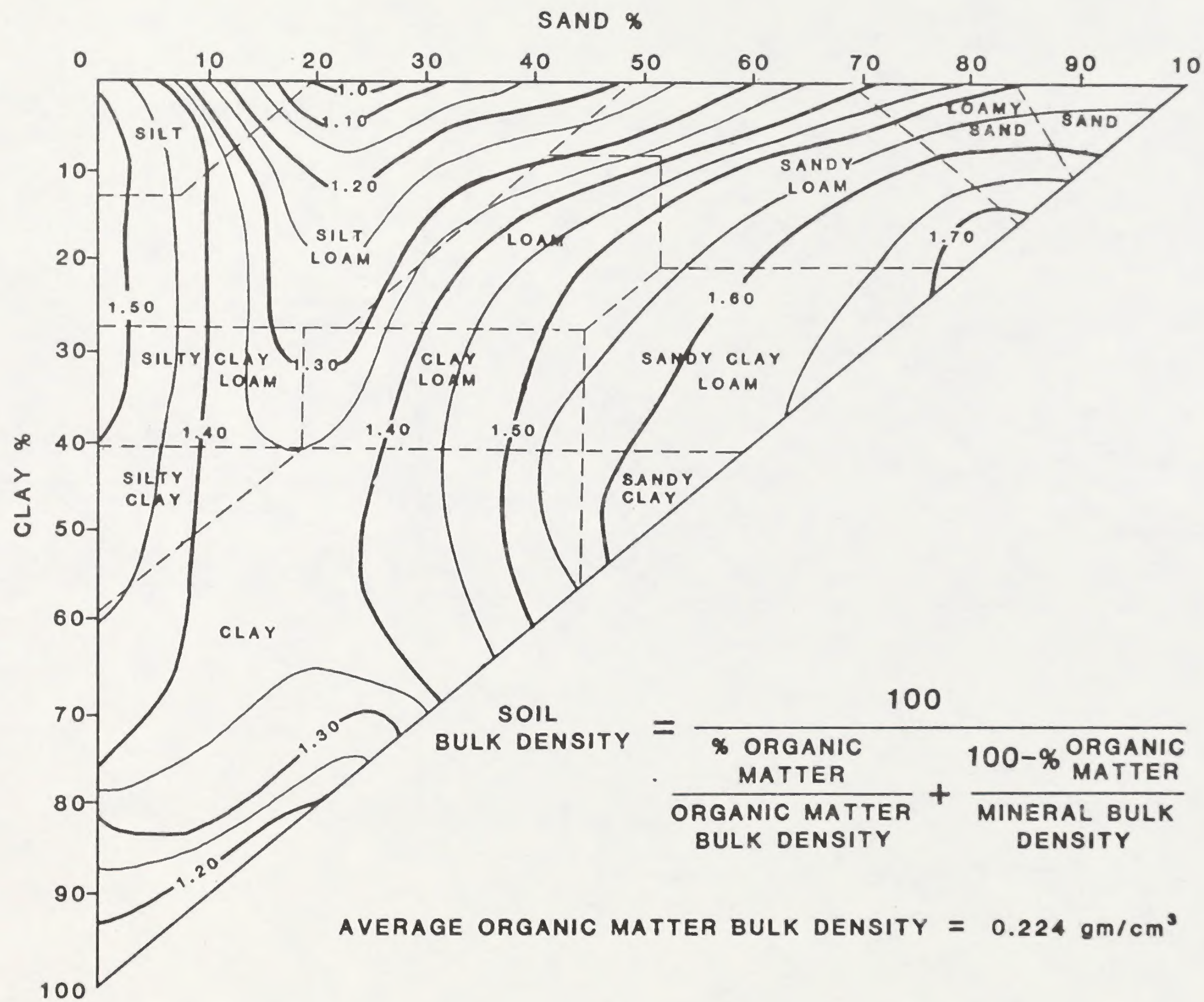


Figure 7.27.--Porosity, (ϕ), cm^3/cm^3.



$$\text{SOIL BULK DENSITY} = \frac{100}{\dfrac{\%\ \text{ORGANIC MATTER}}{\text{ORGANIC MATTER BULK DENSITY}} + \dfrac{100-\%\ \text{ORGANIC MATTER}}{\text{MINERAL BULK DENSITY}}}$$

Figure 7.28.--Mineral bulk density (gm/cm^3).

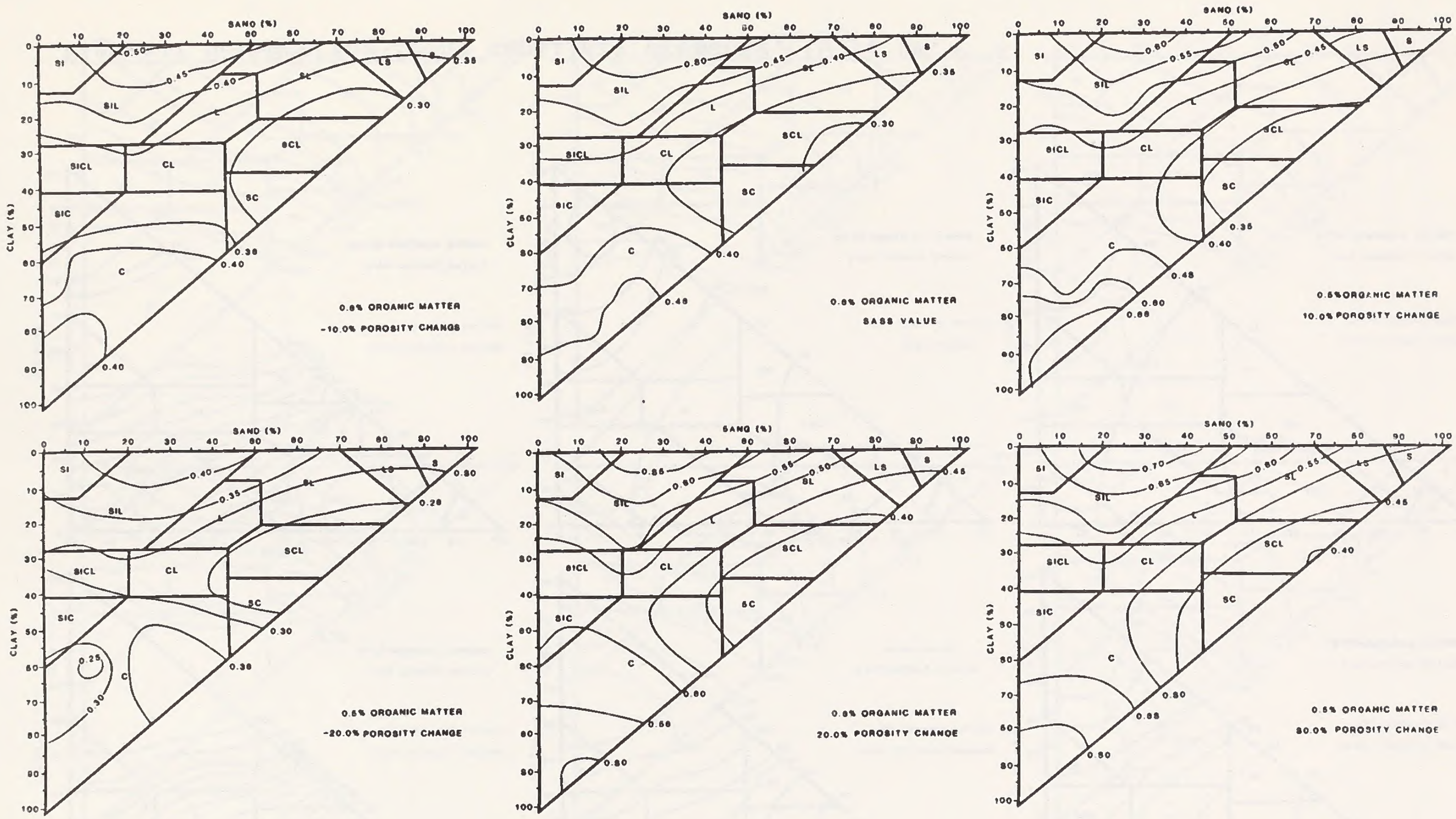


Figure 7.29.--Effective porosity, (Θ_e), cm^3/cm^3.

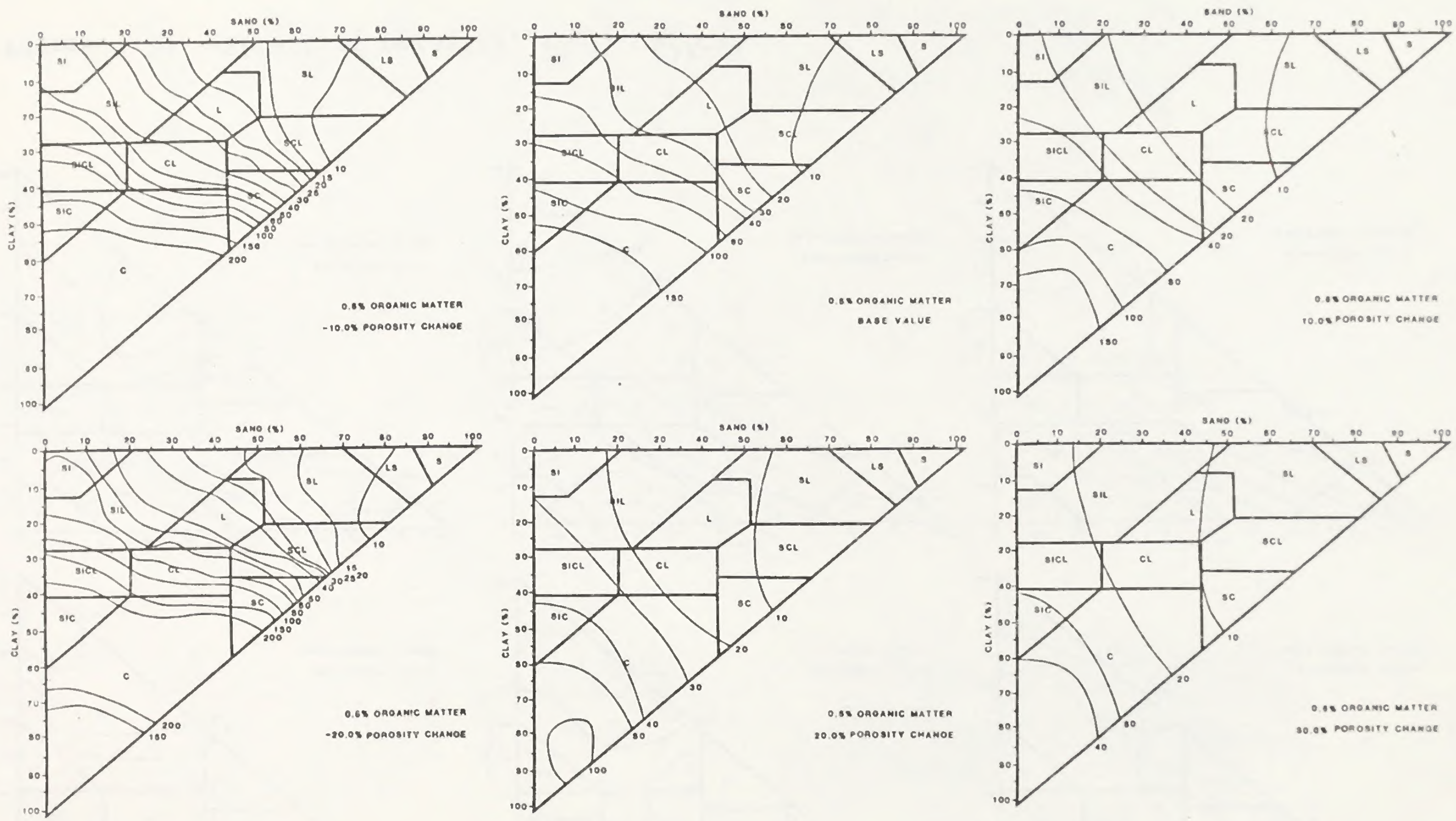


Figure 7.30--Wetting front capillary pressure, (ψ_f), cm.

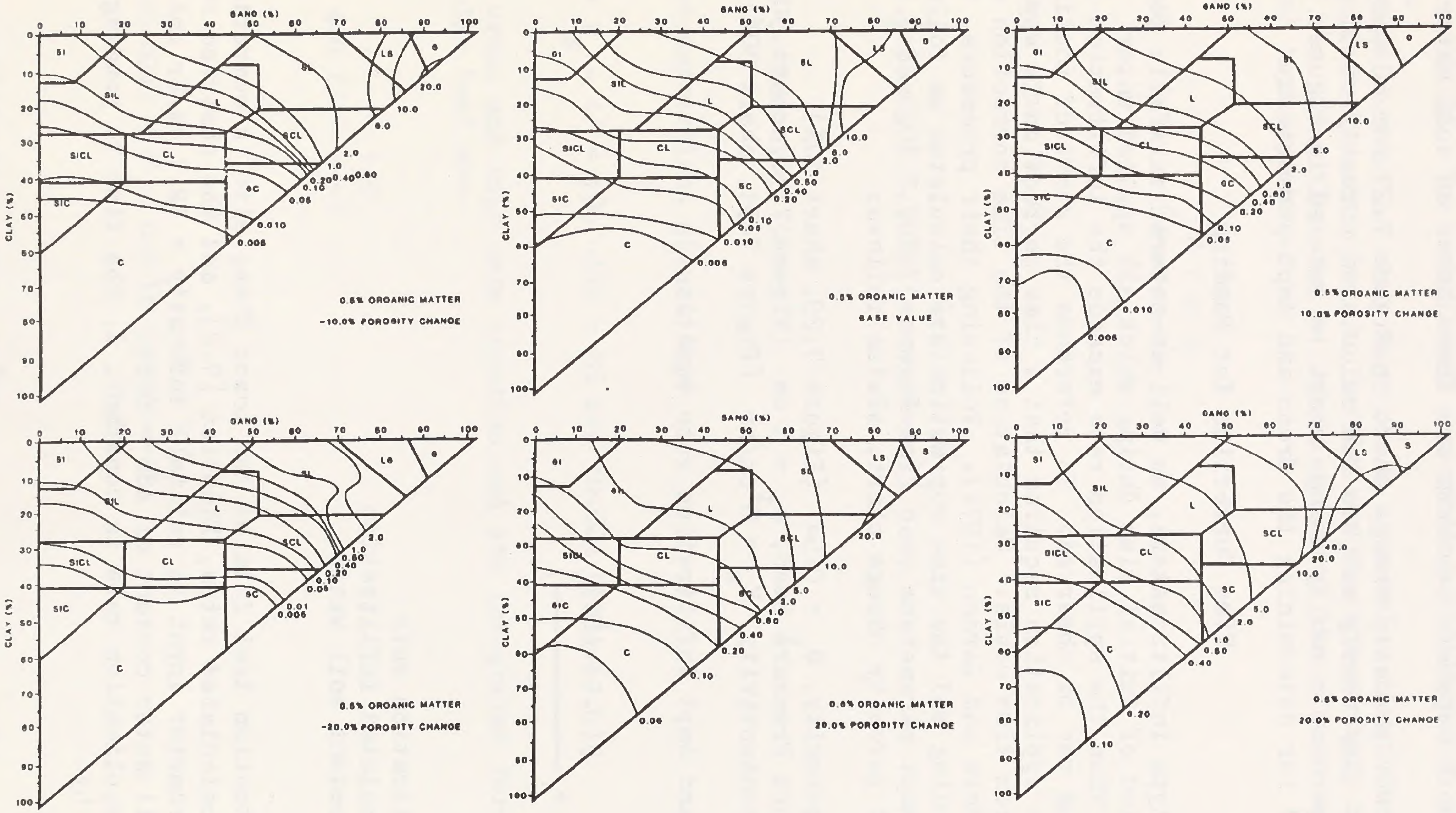


Figure 7.31.--Saturated hydraulic conductivity, (K_s), cm/hr.

soil fabric alone. Thus, how to treat the coarse fragment content of soils for modifying soil water properties requires additional research. In the remainder of this example, the chart calculated bulk density is used and the soil separate percents are those based on soil material less than 2 mm.

The 30 percent porosity change chart in Figure 7.27 for 60 percent sand and 12 percent clay nearly matches the calculated porosity of 58 percent. Thus, the 30 percent porosity change chart is entered in Figures 7.29, 7.30, and 7.31 for determining the Green and Ampt parameters.

Time Correction for Ponding

Sprinkler type infiltrometers, as well as natural rainfall, generally display a period of initial time during which all applied water infiltrates. When the application rate exceeds the infiltration rate, surface ponding can be observed. To reference the start of ponding to the start of water application requires that a time correction is applied to the infiltration time scale. Calculation of the time correction was first described by Mein and Larson (1971). Following their procedure, the time to surface ponding and the time correction are calculated as follows.

Green and Ampt parameters read from Figures 7.29, 7.30, and 7.31, using the 30 percent porosity change chart, are as follows:

Effective porosity, θ_e = 0.54 (Figure 7.29, chart 30%)
Wetting Front Pressure Head, ψ_f = 5 cm (Figure 7.30, chart 30%)
Saturated conductivity, K_s = 8 cm/hr (Figure 7.31, chart 30%).

The Green and Ampt infiltration rate equation is

$$f = 4.0 \left(1 + \frac{5(0.54-ASW)}{F}\right) \qquad [7.2]$$

where

f = infiltration rate
F = accumulated infiltration
ASW = antecedent soil water.

For the infiltration test data at the Lower Sheep site, a comparison was made between calculated rates, Equation [7.2], and the observed rate data.

The infiltrometer input is rainfall intensity = 12.7 cm/hr and an antecedent soil water content of ASW = 0.24.

Since the application rate is constant, I, the time to ponding, t_p, can be calculated by

$$t_p = F_p/I = \frac{\psi_f n}{I(I/K-1)}$$

In our example, t_p was calculated as 195 seconds. The observed time of runoff initiation was 250 seconds. Due to surface depressions and surface roughness, the initiation of runoff is generally later than time of initial ponding. The calculated pre-ponding infiltration amount was F_p = 0.69 cm.

The time correction also requires a time value identified as the time, under saturated conditions, to infiltrate the pre-ponding infiltration amount, t'. This time can be calcualted from the integrated form of the Green and Ampt equation,

$$Kt = F - \psi_f \, n \ln \left(\frac{F + n \psi_f}{n \psi_f} \right) \qquad [7.3]$$

with F set equal to F_p.

$$t' = \frac{1}{4} \left[0.69 - 1.5 \ln \left(\frac{0.69 + 1.5}{1.5} \right) \right]$$

$$t' = 0.0306 \text{ hr (110 sec)}.$$

The time correction, t_c, is thus

$$t_c = t_p - t' = 195 - 110 = 85 \text{ sec (0.024 hrs)}.$$

The Green and Ampt rate equation and its integrated form for this particular test are

$$f = 4.0 \left(1 + \frac{1.5}{F} \right)$$

and

$$4(t - 0.024) = F - 1.5 \ln \left(\frac{F + 1.5}{1.5} \right)$$

where

f = infiltration rate, cm/hr
and F = infiltration amount, cm.

Comparison of the estimated and measured infiltration rates are presented in Table 7.10. Measured infiltration for the 30 minute test was 3.04 cm, while the calculated amount was 3.80 cm. Measured runoff initiation was at 250 sec, while calculated ponding was at 195 seconds. The final rates appear to be converging to the measured rates. Overall, the predicted infiltration rates at the Lower Sheep site on the Reynolds Creek Watershed are quite reasonable.

Special Rangeland Considerations

Characteristics of rangeland soils that may require modifications for the application of the infiltration approach include the effects of coarse fragments (particles >2mm), compaction by grazing animals, and the effects of soil organic matter. The following material presents some initial insights into these considerations. This, of course, is preliminary and requires additional research and testing using rangeland infiltration data.

Compaction

Stephenson, in a four year study on cattle wintering effects on water quality, measured bulk density trends on field sized experimental areas. From replicated plots, it appeared that a concentration of 16 animals/ac decreased total porosity 9 percent and a concentration of 4 animals/ac decreased total porosity 6 percent. It was observed that after removal of animals for one season, the soil porosity returned to its original state.

The presented figures for Green and Ampt parameters with a 10 or 20 percent decrease of total porosity can be used for the compaction case. Infiltration would be calculated assuming that the compacted layer can be modeled similarly to a crusted soil.

Rock Content

Many rangeland soils have a high content of coarse fragments (> 2mm). The influence that these fragments have on the infiltration parameters has not been completely reported. Reported work by Mehuys et al. (1975) indicated that saturated conductivity is markedly affected by stone content. The usual procedure of determining soil retention from the sieved soil sample, excluding the rock fragment, needs to be examined for possible modification of infiltration model parameters. At higher rock contents, the soil water properties determined from the soil fabric may not represent the properties of the bulk soil. Research is needed to clarify the role of rock content in estimating the hydraulic and water storage properties of such soils.

Soil Organic Matter

At some soil sampling sites on the Reynolds Creek Watershed, very high organic contents were measured in the surface layer, i.e., 5 to 10 percent or even higher. This was generally the situation at the higher elevation sites where precipitation amounts are greater. The implication to infiltration based runoff modeling is that infiltration rates and water storage are much higher in soil where organic matter is high. Figure 7.28 developed by Rawls (1983) can be used to estimate bulk densities as a function of organic matter content.

Table 7.10.--Comparison of calculated and experimental infiltration rates.

Time	Calculated infiltration Amount, F	Calculated infiltration rate, f	Experimental infiltration Rate, f
(seconds)	(cm)	cm/hr	cm/hr
195	0.69	12.7	12.7
262	0.90	10.7	10.2
333	1.10	9.5	7.2
500	1.50	8.0	5.8
742	2.00	7.0	5.1
1,012	2.50	6.4	4.9
1,303	3.00	6.0	5.1
1,932	4.00	5.5	4.6

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